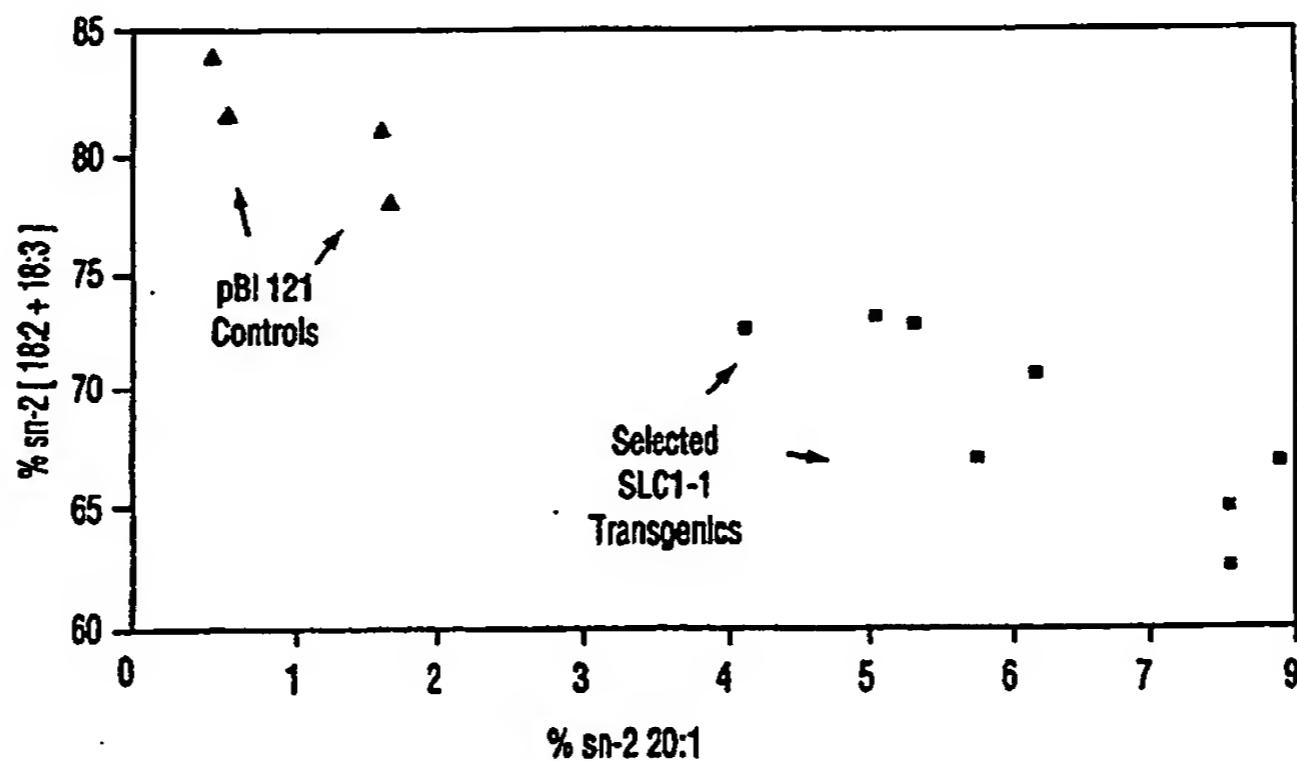




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(54) Title: MODIFICATION OF PLANT LIPIDS AND SEED OILS UTILIZING YEAST SLC GENES



Correlation between decrease in sn-2 polyunsaturated fatty acids and increase in sn-2 eicosenoic acid in *A. thaliana* Control and *SLC1-1* Transgenic T_3 Seeds.

(57) Abstract

This invention relates to the modification of plant lipids and seed oils by genetic engineering techniques to produce oilseeds of enhanced commercial value. In one form, the invention relates to a transgenic oilseed plant, or a seed of such plant, having a genome incorporating an expressible yeast *SLC1-1* or *SLC1* gene. The invention also provides a method of producing a transgenic oilseed plant, which comprises introducing into the genome of the plant an expressible yeast *SLC1-1* or *SLC1* gene. The invention also relates to various plasmids and vectors used in the method of the invention.

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MODIFICATION OF PLANT LIPIDS AND SEED OILS
UTILIZING YEAST SLC GENES

TECHNICAL FIELD

5 This invention relates to the modification of plant lipids and seed oils by genetic engineering techniques. More particularly, the invention relates to a method of genetically modifying oilseed plants to produce oilseeds or whole plants of enhanced commercial value. The invention 10 also relates to the modified plants and seeds, and to genetic materials and vectors used for the production of such plants, and for further modifications of plants.

BACKGROUND ART

There is considerable interest nowadays in modifying 15 the seed oil fatty acid composition and content of oilseeds by molecular genetic means to provide a dependable source of Super High Erucic Acid Rapeseed (SHEAR) oil for use as an industrial feedstock. A similar interest exists for producing other strategic non-edible oils (e.g. seed oils 20 high in hydroxy-, epoxy-, short and medium chain fatty acids, etc.) in traditional oilseed crops (e.g. rapeseed, flax, sunflower, soybean).

For edible oils, there is considerable interest in changing the fatty acid composition (e.g. higher 25 oleic/lower polyunsaturates, lower saturates, higher saturates) as well as increasing the oil content in oilseed crops such as Canola and edible oil flax (Linola), soybean and sunflower.

Currently, there are no documented demonstrations of 30 increases in oil content (yield) by transgenic means, although yield increases by traditional breeding and selection continue to bring about incremental improvements.

In contrast, increases in the proportions of some strategic fatty acids have been achieved by the 35 introduction of various plant fatty acid biosynthesis and acyltransferase genes in oilseeds. Some examples of such processes are the following:

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1. Expression of a medium chain fatty acyl-ACP thioesterase from California Bay, in Brassicaceae to increase the lauric acid (12:0) content (Calgene; 5 Voelker et al., 1995; 1996 - see References 35 and 36 in the accompanying "References Pertinent to the Present Invention").
- 10 2. Expression of a *Jojoba* β -ketoacyl-CoA synthase in low erucic acid *Brassica napus* (Canola) cultivars to increase the level of erucic acid; the effect following expression in high erucic acid cultivars was negligible (Calgene; Lassner et al., 1996 - see Reference 20).
- 15 3. Expression of an anti-sense construct to the stearoyl-ACP $\Delta 9$ desaturase in Brassicaceae to increase the stearic acid content (Calgene; Knutzon et al., 1992 - see Reference 16).
- 20 4. Increased proportions of oleic acid in *B. napus* by co-suppression using a sense construct encoding plant microsomal FAD2 ($\Delta 12$) desaturase (duPont/InterMountain Canola; Hitz et al., 1995 - see Reference 12).
- 25 5. Increased proportions of 12:0 or 22:1 in the sn-2 position of triacylglycerols (TAGs) in rapeseed by expression of coconut or meadowfoam lyso-phosphatidic acid acyltransferases (LPATs; E.C. 2.3.1.51), 30 respectively (Calgene; Knutzon et al., 1995 a & b; - see References 17 and 18; Lassner et al., 1995 - see Reference 21).
- 35 Although the use of plant transgenes resulted in altered proportions of sn-2 lauric and erucic acids, in

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laurate canola and high erucic acid rapeseed, respectively, the overall proportions of lauric and erucic acids in the seed oil were not increased, and there was no evidence of increased total fatty acid content, or increased oil yield 5 in these transgenics.

There is accordingly a need for new ways of increasing oil yield and improving oil composition in oilseed plants by employing genetic engineering techniques.

DISCLOSURE OF INVENTION

10 An object of the present invention is to genetically modify oilseed plants to improve the commercial value of such plants, the seeds of such plants, and the oils produced from such plants.

Another object of the invention is to provide a method 15 of modifying the yield and composition of oils derived from oilseed plants.

The present invention is based on the discovery that sn-2 acylglyceride fatty acyltransferase genes (*SLC1-1* and its allele, *SLC1*) from yeast (*Saccharomyces cerevisiae*), 20 can be used to change the oil content and oil composition of plant seed and leaf lipids.

Thus, according to one aspect of the present invention, there is provided a transgenic oilseed plant having a genome incorporating an expressible yeast *SLC1-1* 25 or *SLC1* gene.

According to another aspect of the invention, there is provided a seed of a transgenic oilseed plant having a genome incorporating an expressible yeast *SLC1-1* or *SLC1* gene.

30 According to yet another aspect of the invention, there is provided a method of producing a transgenic oilseed plant, which comprises introducing into the genome of said plant an expressible yeast *SLC1-1* or *SLC1* gene.

The invention also relates to various plasmids and 35 vectors used in the method of the invention, and to the co-

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introduction of other genes into plants modified to include the *SLC1-1* and *SLC1* genes.

The advantages of the present invention include the fact that the yeast *SLC1-1* and *SLC1* genes can be used to 5 increase the oil content and to change total fatty acid composition, as well as to alter the acyl composition of TAGs, including the *sn*-2 position, and to change the relative proportions of TAG species, in various oilseed plants, e.g. *Arabidopsis thaliana*, in high erucic acid and 10 canola cultivars of *Brassica napus*, and in *Brassica carinata*.

Moreover, the yeast *sn*-2 acyltransferase (*SLC1-1* and *SLC1* genes) can be utilized in high erucic acid Brassicaceae to increase the oil content and to produce 15 seed oils with increased content of very long-chain fatty acids (VLCFAs) and TAGs with an altered stereospecific composition with respect to very long chain fatty acids. Thus, in contrast to previous results utilizing plant transgenes (as mentioned above), the current invention 20 utilizing a yeast transgene is capable of achieving combined increases in seed oil content, seed erucic acid content and overall proportions of erucic acid in the seed oil.

The yeast *sn*-2 acyltransferase (*SLC1-1* and *SLC1* genes) 25 can also be utilized in edible oil cultivars (Canola-quality cultivars) of the Brassicaceae, to increase the oil content and to produce seed oils with altered proportions of oleic acid, polyunsaturated fatty acids and very long chain saturated fatty acids.

30 The related yeast *SLC1-1* and *SLC1* alleles can be utilized in the same ways. Both alleles encode an *sn*-2 acyltransferase; *SLC1* differs from *SLC1-1* only in the amino acid at position 44 (Glutamine, Q) compared to *SLC1-1*, where the amino acid at position 44 is Leucine (L).

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The *SLC1-1* and *SLC1* transgenic plants can be used as host germplasm for further down-regulation of indigenous plant acyltransferases.

To achieve directed assembly of TAG biosynthesis to produce stereospecifically-designed TAGs, the co-ordinated expression of a number of biochemical reactions, including that mediated by LPAT, is required. One of the distinct possibilities with respect to optimizing transgenic expression of foreign LPATs to synthesize TAGs with new acyl compositions (e.g. increased very long chain fatty acids at the *sn*-2 position), is the possible need to simultaneously down-regulate the indigenous LPAT already present in the transgenic host (e.g. an LPAT which normally prefers to insert polyunsaturated C₁₈ fatty acyl groups into the *sn*-2 position). The overall homologies between the yeast *sn*-2 acyltransferases and published plant *sn*-2 acyltransferases (LPATs) are low, and are restricted mostly to the C-termini of the proteins. In contrast, the plant acyltransferases have much greater overall homology to each other, and regions of homology extend throughout the sequence. Therefore, the use of the yeast *SLC* genes to achieve the effects described herein, allow a unique opportunity to further improve these traits in a way not possible when the initial transformation was performed with a plant acyltransferase. In effect, the limited homology between plant and the yeast *sn*-2 acyltransferases are low enough to allow strategies to down-regulate the host plant LPAT by conventional means (e.g. anti-sense RNA technology or a co-suppression phenomenon; Mol et al., 1990; Van Blokland et al., 1993; De Lange et al., 1995) without a concomitant negative impact on the expression of the yeast transgene or on plant seed development. Thus, the yeast transgene strategy has a distinct advantage over that in which another plant transgene is introduced into a host plant where there is a highly homologous, indigenous LPAT.

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The yeast *sn-2* acyltransferase (*SLC1-1* and *SLC1* genes) can be used to increase the oil content and alter the acyl composition of TAGs in all other oilseeds including borage (*Borago* spp.), castor (*Ricinus communis*), cocoa bean 5 (*Theobroma cacao*), corn (*Zea mays*), cotton (*Gossypium* spp.), *Crambe* spp., *Cuphea* spp., flax (*Linum* spp.), *Lesquerella* and *Limnanthes* spp., nasturtium (*Tropaeolum* spp.), *Oenothera* spp., olive (*Olea* spp.), palm (*Elaeis* spp.), peanut (*Arachis* spp.), safflower (*Carthamus* spp.), soybean 10 (*Glycine* and *Soja* spp.), sunflower (*Helianthus* spp.), tobacco (*Nicotiana* spp.) and *Vernonia* spp.

The yeast *sn-2* acyltransferase (*SLC1-1* and *SLC1* genes) oilseed transformants can be utilized, by a second transformation, with all other value-added fatty acid 15 biosynthesis genes (e.g. the hydroxylase gene from castor or *Lesquerella* spp.), or by crossing with related oilseed transformants already containing such value-added genes, to produce seed oils with increased amounts of value-added fatty acids (e.g. increased hydroxy fatty acid content and 20 altered TAG composition with respect to those containing hydroxy fatty acids).

The *SLC1-1* gene and related *SLC1* allele, can be utilized to modify fatty acid and lipid profiles in vegetative tissues to improve tolerance to biotic and 25 abiotic plant stresses (e.g. increased membrane fluidity in root and leaf tissues to improve frost tolerance).

The use of the yeast *SLC1-1* gene and the *SLC1* allele in plants, to bring about changes in overall lipid content and composition, has not been previously disclosed or 30 demonstrated (reduced to practice) as a means for manipulating the relative proportions or amounts of fatty acids (e.g. very long chain fatty acids), and also for increasing the oil content of crops producing edible or industrial oils.

35 Previously, there have been no demonstrations of increases in oil yields brought about by transgenic means.

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More specifically, there was no previous evidence that yeast acyltransferases, the enzymes responsible for synthesizing triacylglycerols, have been expressed in plants to alter oil composition or content.

5 In contrast, however, a decrease in diacylglycerol acyltransferase activity in a mutant of *Arabidopsis thaliana* resulted in a decrease in oil yield and a change in acyl composition (Katavic et al., (1995) *Plant Physiology*, 108:399-409 - see Reference 15).

10 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows the nucleotide [SEQ ID NO:1] and deduced amino acid sequence [SEQ ID NO:2] of the coding region of the yeast *SLC1-1* gene used in the present invention, the stop codon being identified by "@", and a highly conserved 15 consensus sequence among bacterial and yeast *sn-2* acyltransferases being underlined;

Fig. 2 shows the nucleotide [SEQ ID NO:3] and deduced amino acid sequence [SEQ ID NO:4] of the coding region of the yeast *SLC1* gene used in the present invention, the stop 20 codon being identified by "@", and a highly conserved consensus sequence among bacterial and yeast *sn-2* acyltransferases being underlined;

Fig. 3 shows a strategy for constructing an *SLC1-1* plant transformation vector explained in the Experimental 25 Details provided later, the salient features not being drawn to scale; and

Figs. 4 to 7, as well as Tables 1-20 below, show the results of tests explained in the Experimental Details provided later.

30 BEST MODES FOR CARRYING OUT THE INVENTION

The sequences of the *SLC1-1* gene [SEQ ID NO:1] and the *SLC1* allele [SEQ ID NO:3], and their derived peptide structures [SEQ ID NOS: 2 and 4], are as shown in Figs. 1 and 2, respectively.

35 The yeast *SLC1* gene (and related *SLC1-1* suppressor allele gene) have been characterized in two publications,

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as follows (the disclosures of which are incorporated herein by reference):

1. Lester, R.L., Wells, G.B., Oxford, G. and
5 Dickson, R.C. (1993) Mutant strains of *Saccharomyces cerevisiae* lacking sphingolipids synthesize novel inositol glycerolipids that mimic sphingolipid structures. *J. Biol. Chem.* 268: 845-856 - Reference 22; and
- 10 2. Nagiec, M.M., Wells, G.B., Lester, R.L., and Dickson, R.C. (1993) A suppressor gene that enables *Saccharomyces cerevisiae* to grow without making sphingolipids encodes a protein that resembles an *Escherichia coli* fatty acyltransferase. *J. Biol. Chem.* 268: 15 22156-22163 - Reference 25.

The DNA and amino acid sequences for the coding region of the *SLC1-1* gene are stored in GenBank/EMBL under accession No. L13282 (the stored sequence including a 5' 20 untranslated region not disclosed in the present application).

The *SLC1* gene was originally cloned from a yeast mutant lacking the ability to make sphingolipids. The mutant allele of *SLC1* was shown to encode a protein which 25 suppresses the genetic defect in sphingolipid long chain base biosynthesis. The gene sequence of *SLC1* is homologous to the *E. coli* *PLSC* gene, which has been claimed to encode lyso-phosphatidic acid acyltransferase (LPAT; an acyltransferase acylating the *sn*-2 position of lyso- 30 phosphatidic acid (LPA) to give phosphatidic acid (PA)). The *SLC1* gene was able to complement the growth defect in JC201 (an *E. coli* strain mutated in *PLSC*). Based on the observation that *SLC* strains grown in the absence of long chain base make novel phosphatidylinositol derivatives 35 (Lester et al., (1993) *J. Biol. Chem.* 268: 845-856.), one

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possible conclusion by the authors was that the *SLC1* encodes a protein capable of acylating the *sn*-2 position of inositol-containing glycerolipids (i.e. perhaps an lyso-phosphatidyl-inositol acyltransferase, LPIT). Based on 5 these findings, it was reported that *SLC1* encodes a yeast *sn*-2 acyltransferase. However, the authors of the paper (Dickson, Lester et al.), were unable to detect LPAT activity in the complemented *E. coli* JC201 mutant.

In the Nagiec et al. paper, the authors also reported 10 the sequence of the gene for a suppressor allele designated *SLC1-1* in which nucleotide 131 has a T instead of an A, resulting in an amino acid change at position 44, from a glutamine to a leucine. The working hypothesis is that the *SLC1-1* suppressor allele encodes a variant acyltransferase 15 with an altered substrate specificity, which enables it to use a very long-chain fatty acid (26:0) to acylate the *sn*-2 position of inositol-containing glycerolipids. The authors have not, to date, provided conclusive evidence of activity encoded by *SLC1-1* or *SLC1*.

20 Based on the interest of the inventors of the present invention in modifying the very long-chain fatty acid (VLCFA) content of Brassicaceae, the inventors obtained plasmid *p411* *Δ B/C* containing the *SLC1-1* suppressor allele gene from Dr. Dickson at the University of Kentucky, 25 Lexington, Kentucky, USA. The inventors also believed that expressing the foreign gene in a plant might lead to more information on the nature of what *SLC1-1* and *SLC1* encode. Work carried out by the inventors identified, for the first time, using the model oilseed *Arabidopsis thaliana*, 30 transformants with increased seed oil content, and increased proportions of TAGs containing very long-chain fatty acids (VLCFAs = > C₁₈). In addition, there are increased proportions of VLCFAs at the *sn*-2 position of TAGs, and a concomitant decrease in the proportion of 35 polyunsaturated fatty acids esterified at this position.

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SLC1-1 transformants of *B. napus* cv. Hero and *B. carinata* (both high erucic acid cultivars) show increased oil content and increased erucic acid content/mg dry weight (DW) of seed. *SLC1-1* transformants of *B. napus* cv. Westar 5 (Canola-quality cultivar) show increased proportions of oleic acid (18:1) and decreased proportions of polyunsaturated fatty acids (18:2 and 18:3).

The *SLC1-1* and *SLC1* genes can be introduced into the genomes of oilseed plants and expressed using conventional 10 genetic engineering techniques. For example, transformation could involve the use of *Agrobacterium Ti* plasmid-mediated transformation (e.g. in planta, vacuum infiltration, cotyledonary or hypocotyl petiole wound infection, or particle bombardment, etc). Constructs may 15 be driven by constitutive or tissue-specific promoters, as will be apparent to persons skilled in the art.

Broad applicability of the invention to oilseed plants of various kinds is to be expected because oil synthesis follows the same or closely related biochemical pathways in 20 all such plants (see References 29, 30, 37, 38, 39 and 40).

The present invention will be described in more detail with reference to the following experimental details, which provide specific illustration. It should be kept in mind, however, that the present invention is not limited to the 25 details presented below.

EXPERIMENTAL DETAILS

CONSTRUCTION OF VECTORS FOR *SLC1-1* TRANSFORMATION

Following the cloning strategy illustrated in Fig. 3 30 of the accompanying drawings, two primers with 5' BamHI restriction site extensions, OM087 (AGAGAGAGGGATCCATGAGTGTGATAGGTAGG) [SEQ ID NO: 5] and OM088 (GAGGAAGAAGGATCCGGGTCTATATACTACTCT) [SEQ ID NO: 6], designed according to the 5' and 3' end sequences of the *SLC1* gene 35 [SEQ ID NO:3], respectively, were used in a Polymerase Chain Reaction (PCR) with plasmid p411 Δ B/C (obtained from

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Dr. Dickson at the University of Kentucky, Lexington, Kentucky, USA), harboring the suppressor allele of the *SLC1* gene (*SLC1-1*) as template, to generate the *SLC1-1* PCR fragment with a BamHI site at both ends. The (*SLC1-1*) PCR 5 fragment, therefore, represents the suppressor allele of the *SLC1* gene with nucleotide T substituting for nucleotide A at position 131, resulting in an amino acid residue change from glutamine to leucine at residue 44. The fragment was digested with BamHI and ligated into the BamHI 10 cloning site located between the tandem 35S promoter and NOS terminator in vector pBI524 (obtained from Dr. Raju S.S. Datla, NRC Plant Biotechnology Institute, 110 Gymnasium Place, Saskatoon, Saskatchewan, Canada, S7N 0W9; published by Datla et al., 1993 - see Reference 9) to give 15 vector *SLC1-1-pBI-524*. The orientation of *SLC1-1* in the vector *SLC1-1-pBI-524* was verified by restriction digestion with BglII which cuts *SLC1-1* at nt 377 from the 5' end and immediately downstream of the 35S promoter in vector pBI524. The translation initiation codon of *SLC1-1* is 20 maintained, and hence the construct is a transcriptional fusion. The HindIII and EcoRI fragment containing a tandem 35S promoter, AMV enhancer, *SLC1-1* encoding sequence and NOS terminator was freed from *SLC1-1-pBI-524*, and cloned 25 into the EcoRI-HindIII site of vector RD400 (also obtained from Dr. R. Datla; published by Datla et al., 1992 - see Reference 8). The final vector p*SLC1-1/pRD400* (deposited on May 9, 1996 under the terms of the Budapest Treaty at the American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD 20852, USA; under deposit no. ATCC 97545) was 30 introduced into *Agrobacterium tumefaciens* strain GV3101 (bearing helper plasmid pMP90; Koncz and Schell, 1986) by electroporation.

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MOLECULAR BIOLOGICAL TECHNIQUES

Unless otherwise stated, all molecular biological techniques were carried out by methods generally prescribed by Ausubel et al., (1995).

5

PLANT GROWTH CONDITIONS

All *A. thaliana* control and transgenic plants were grown at the same time, in controlled growth chambers, under continuous fluorescent illumination (150-200 μE $10 \text{ m}^{-2} \cdot \text{sec}^{-1}$) at 22°C, as described by Katavic et al., (1995).

All other control and transgenic plants of the Brassicaceae (*B. napus*, *B. carinata*) were grown at the same time, in the P.B.I. Transgenic Plant Center greenhouse under natural light supplemented with high pressure sodium lamps (HPS 15 lamps) with a 16 hour photoperiod (16 h light/8 h dark), at 22°C, and a relative humidity of 25-30%.

PLANT TRANSFORMATION

The *SLC1-1/RD400* construct was tested in *A. thaliana* by *in planta* transformation techniques, and in both high and low erucic acid *B. napus* cultivars, and *B. carinata* (by co-cultivation transformation of cotyledonary petioles and hypocotyl explants with *A. tumefaciens* bearing the *SLC1-1* construct).

25

Testing the *SLC1-1* construct in *A. thaliana*

Wild type (WT) *A. thaliana* plants of ecotype Columbia were grown in soil. *In planta* transformation was performed by wound inoculation (Katavic et al. 1994) or vacuum infiltration (Bechtold et al. 1993) with overnight bacterial suspension of *A. tumefaciens* strain GV3101 bearing helper nopaline plasmid pMP90 (disarmed Ti plasmid with intact *vir* region acting *in trans*, gentamycin and kanamycin selection markers; Koncz and Schell (1986)) and binary vector *pSLC1-1 /pRD400*.

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After inoculation or infiltration, plants were grown to set seeds (T₁). Dry seeds (T₁) were harvested in bulk and screened on selective medium with 50 mg/L kanamycin. After two to three weeks on selective medium, 5 seedlings were transferred to soil. Leaf DNA was isolated from kanamycin-resistant T₁ plants and analysed by PCR amplification of the SLC1-1 fragment. Developing leaves from T₁ plants as well as T₂ mature seeds from SLC1-1 transgenic lines were used for lipid and biochemical analyses. Developing leaves and mature seeds from untransformed wild type (WT) Columbia plants and pBI121 transgenic plants (binary vector pBI121, containing only kanamycin selection marker and GUS reporter gene; Jefferson et al., 1987) were used as controls in analyses of seed lipids. Based on these analyses, T₂ seeds of lines exhibiting changed acyl composition and/or lipid content were grown on selective medium (to eliminate homozygous WT segregants) and then transferred to soil to yield T₃ seed populations.

20

Testing the SLC1-1 construct in *Brassica napus* and *Brassica carinata* :

Transformation experiments were also performed on B. napus cv. Westar (canola variety, low erucic acid), B. napus cvs. Hero, Reston and Argentine (all high erucic acid varieties) and B. carinata (breeding line C90-1163, a high erucic acid line) by co-cultivation of cotyledonary petioles and hypocotyl explants with *A. tumefaciens* bearing the SLC1-1/RD400 construct. Transformation methods according to Moloney et al. (1989) and DeBlock et al. (1989) were modified to optimize transformation conditions.

Modifications of the cotyledonary-petiole transformation method (Moloney et al., 1989) included the introduction of a 7-day explant-recovery period following co-cultivation, on MS medium with the hormone benzyladenine

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(BA) and the antibiotic timentin, for elimination of *Agrobacterium*.

Modifications of the hypocotyl-explant transformation method (DeBlock et al.; 1989) included: (1) preculture of 5 explants on agar-solidified MS medium with the hormones 2,4-dichlorophenoxyacetic acid (2,4-D) and kinetin (K); (2) co-cultivation of hypocotyl explants with *Agrobacterium* in petri dishes with the same medium as for preculture, on sterile filter paper; (3) following co-cultivation, a 7-day 10 explant-recovery period on medium with hormones (2,4-D and K), and with timentin for *Agrobacterium* elimination, (4) regeneration of transgenic shoots on MS medium with the hormones benzyladenine (BA) and zeatin (Z), the ethylene inhibitor silver nitrate (AgNO₃), and antibiotics timentin 15 (for *Agrobacterium* elimination) and kanamycin (for transformed-cell/shoot selection).

Green shoots were rooted and transferred to soil. Genomic DNA was isolated from developing leaves and PCR analyses and Southern analyses (Southern, 1975) were 20 performed. Seeds (T₁) from transgenic plants were harvested and from each transgenic line, ten T₁ plants were grown in soil. Mature seeds (T₂) from these plants were harvested and subjected to lipid and biochemical analyses.

25 LIPID ANALYSES AND ACYLTRANSFERASE (LPAT) ASSAYS

Analyses of Leaf and Seed Lipids from SLC1-1 and WT/pBI121 Transgenics and Untransformed WT plants

30 Lipids were isolated from mature seed and developing leaves as described previously (Taylor et al., 1992; Katavic et al., 1995) and analyzed by GC for total fatty acid content and fatty acid composition. Triacylglycerol species were analyzed by high-temperature GC as described 35 by Katavic et al., 1995. Stereospecific analyses of TAGs

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were performed on intact seed lipids (chiefly TAGs) as described by Taylor et al., 1994, 1995 a & b).

LPAT assays

5

For leaf assays, leaves at mid-expansion were chosen from control and *SLC1-1* transgenic plants, and leaf tissue sampled from several leaves with a cork-borer. For developing seed assays, in *A. thaliana* 25-30 siliques were harvested at mid-seed development (15-18 d.p.a.) to give developing T_3 seed samples from both controls (untransformed WT and pBI121-transformed) and selected *SLC1-1* transgenics. *B. napus* and *B. carinata* T_2 embryos at the mid-cotyledonary stage of development were harvested from 3 siliques of 15 control and selected *SLC1-1* transgenic plants. All plant material was frozen immediately in liquid nitrogen and stored at -70°C until homogenized. Homogenates of both plant leaf and developing seed tissues were prepared and LPAT assays conducted as described by Taylor et al., 20 (1995b).

All protocols with respect to yeast strains were carried out as described by Ausubel et al., (1995, Unit 13.1 Basic Techniques of Yeast Genetics). Wild-type *S. cerevisiae* and *S. pombe* strains were cultured in YPD medium 25 at 28°C at 270 r.p.m. overnight. At mid-log phase, cells were sampled, pelleted by centrifugation at 5,000 r.p.m. for 5 min, and resuspended in 100 mM Hepes-NaOH, pH 7.4. Cell lysates were prepared using acid-washed glass beads as described by Ausubel et al., 1995 (Unit 13.1, Section 30 13.13.4).

LPAT assays were conducted at pH 7.4, with shaking at 100 r.p.m., in a water bath at 30°C for 10-30 min. Assay mixtures (0.5 mL final volume) contained protein (10-200 35 µg, depending on the tissue/extract), 90 mM Hepes-NaOH, 0.5

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mM ATP, 0.5 mM CoASH, 2 mM spermidine, 45 μ M 18:1-LPA, and either 18 μ M [$1-^{14}\text{C}$]-18:1-CoA, [$1-^{14}\text{C}$]-20:1-CoA, or [$1-^{14}\text{C}$]-22:1-CoA (each at a specific activity of 10 nCi/nmol) as the acyl donor. All other conditions for the measurement of LPAT activity are as detailed in Taylor et al (1995b).

^1H -NMR of Mature Seeds

^1H -NMR analyses for relative oil yield (Alexander et al., 1967; Rutar, 1989) were carried out on intact seeds of control and SLC1-1-transformed *B. napus* cv. Hero, and *B. carinata*, using a Bruker AM wide-bore spectrometer operating at 360 MHz. To reduce anisotropic line broadening, the seeds (35/sample) were rotated at 1 kHz in a zirconium rotor oriented 54.7° to the magnetic field (magic angle sample spinning, MASS).

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RESULTS**Acyl-CoA Specificity of Yeast (*S. cereviseae*; *S. pombe*)
5 *sn*-2 Acyltransferase (LPAT)**

Yeast cell lysates from both *S. cereviseae* and *S. pombe* were assayed for relative *sn*-2 acyltransferase activity utilizing 18:1 LPA as an acyl acceptor and different 10 radiolabeled acyl-CoAs. The acyl-CoA specificity of the yeast LPATs *in vitro* was quite broad, and the LPAT was capable of inserting both indigenous (16:0, 18:1) and non-indigenous (18:2, 18:3, 20:1, 22:1 and ricinoleoyl) acyl groups into the *sn*-2 position of 18:1 LPA, as shown in 15 Table 1 below:

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Table 1

Relative *S. cerevisiae* and *S. pombe* acyl-CoA:
LPAT activities using 45 μ M 18:1-LPA
as acyl acceptor

^{14}C -Acyl-CoA supplied (18 μ M)	LPAT Activity nmol/min/mg protein	LPAT Activity relative to 18:1-CoA (%)
<u>S. cerevisiae</u>		
18:1-CoA	3.75	100
18:2-CoA	3.54	94.5
18:1 Δ 12-OH-CoA	1.90	50.7
20:1-CoA	1.92	51.3
22:1-CoA	0.33	8.9
<u>S. pombe</u>		
18:1-CoA	1.50	100
18:2-CoA	1.27	84.7
18:1 Δ 12-OH-CoA	0.85	56.7
20:1-CoA	0.38	25.3
22:1-CoA	0.60	40.0

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Because the yeast LPAT (*sn*-2 acyltransferase) has a relatively broad specificity, transformation of oilseeds rich in very long-chain fatty acids (*A. thaliana*, *B. napus*) with the yeast *SLC1-1* gene can be predicted to result in 5 enriched VLCFA content, including the *sn*-2 position. In addition, yeast *SLC1* and *SLC1-1* transformants can be predicted to be excellent hosts for transformation with hydroxylase genes from castor (*R. communis*) and *Lesquerella* spp. to produce seed oils enriched in hydroxy fatty acids. 10 Alternatively, hydroxylase transformants may be sexually crossed with *SLC1-1* or *SLC1* transformants.

A. thaliana SLC1-1 Transformant Seed Lipid Analyses:

15 Data from *Arabidopsis thaliana* transformation indicates that the gene has a dramatic effect on the total seed lipid content and *sn*-2 composition of TAGs. A large number of *SLC1-1* T₂ transgenic lines (21 of 48) showed significantly increased oil yields over untransformed 20 controls, and pBI121 (without *SLC1-1* insert) controls, as shown in Table 2 below:

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Table 2

Seed fatty acid contents of untransformed wild-type (u-WT) *A. thaliana*, pBI121(-*SLC1-1*) *A. thaliana* transformants (Controls) and selected T₂ transgenic lines of *A. thaliana* transformed with the yeast *SLC1-1* gene.
(Values are fatty acid content (μg)/50 seeds).

Line	16:0	18:0	18:1	18:1c1	18:2	18:3	20:0	20:1	20:2	22:0	22:1	24:0	+ Total
	c9		c9				c9			c9		c9	24:1
u-WT	28.2	12.2	50.5	5.7	101.1	71.9	7.7	74.8	8.7	1.9	8.3	1.3	372.5
Control													
pBI121	28.4	12.4	54.2	4.1	99.9	66.2	6.7	74.0	7.1	tr*	7.2	tr*	360.2
Control													
3	28.8	12.3	57.4	5.7	114.1	78.8	7.7	82.5	9.6	5.7	8.6	1.7	412.3
7	37.1	18.4	102.9	5.9	111.6	84.4	7.6	71.8	8.0	2.9	7.7	2.7	461.0
16	33.0	12.5	62.0	6.2	131.7	95.0	9.0	96.4	12.6	1.7	11.0	2.0	473.0
20	36.3	16.1	87.7	7.6	153.3	95.9	10.7	118.8	11.6	2.5	12.4	3.3	556.4
21	32.1	14.6	62.5	6.2	121.3	89.1	9.4	89.3	9.9	2.2	9.7	2.4	448.5

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21

22	31.9	13.0	57.3	5.9	113.9	86.7	8.6	85.8	10.2	1.7	9.6	2.0	426.5
23	35.4	15.7	72.5	7.5	139.7	95.6	10.5	106.9	12.5	2.3	11.7	2.6	512.7
26	32.6	14.5	67.2	6.4	124.1	87.6	9.7	94.4	10.3	2.3	9.7	2.3	461.1
29	29.3	13.5	57.7	6.4	114.0	81.6	9.4	89.5	10.6	1.9	11.0	2.0	426.7
39	32.2	13.7	72.8	6.3	129.3	82.0	8.9	100.2	9.7	2.3	10.3	2.1	469.7
42	24.4	11.7	58.6	5.2	123.0	83.0	11.8	103.6	11.8	2.6	17.4	3.3	456.2
52	33.4	15.1	78.3	6.5	116.9	57.8	11.2	110.0	9.0	2.5	12.6	3.0	456.2
54	33.0	14.0	73.1	6.8	131.3	91.2	10.1	119.5	11.5	3.0	11.6	1.3	506.3

tr* = trace; < 0.2 wt%

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In certain of these *SLC1-1* T_2 lines, the proportion of VLCFA-containing TAGs (e.g. in Tables 3 and 4), and hence, seed content of total VLCFAs, especially eicosenoic acid and erucic acid, were dramatically increased (Table 5). In 5 some cases, the overall proportions of VLCFAs were also increased (Table 6).

Those *SLC1-1* transformed T_2 lines showing the most promising results in terms of increased oil content and increased proportions of VLCFA-containing TAGs, were 10 selected and individual seeds planted to give T_3 progeny lines. Lipid analyses of TAGs from several independent *SLC1-1* transgenic T_3 lines indicated that there was significantly increased total lipid content (reported as μg fatty acids/100 seeds; Table 7) which correlated with 15 increased TAG content (nmol TAG/100 seeds; Table 8), compared to pBI121 Control T_3 transformants. In particular, the amounts of VLCFAs ($\mu\text{g}/100\text{seeds}$; Table 7) and levels of VLCFA-containing C_{58} and C_{60} TAGs (Table 8), were greatly enhanced in several *SLC1-1* transformants, over 20 pBI121 control plants.

Stereospecific analyses of TAGs from selected independent T_3 *SLC1-1* transgenics contained increased proportions of VLCFAs (e.g. eicosenoic acid, 20:1) at the *sn*-2 position. This trend was consistent, regardless of 25 whether the data was expressed as the proportion, among all *sn*-2 position fatty acids, which is represented by eicosenoic acid, or as the proportion of total eicosenoic acid in TAGs which is found at the *sn*-2 position (Table 9). Furthermore, in the *SLC1-1* transgenics, the increase in 30 proportions of VLCFAs (e.g. eicosenoic acid) at the *sn*-2 position of TAGs was correlated with a concomitant decrease in the proportions of polyunsaturated fatty acids at this position, in comparison to pBI121 control plants (Fig. 4).

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Table 3

TAG Species Accumulating in T₂ Seeds of Untransformed WT Control *A. thaliana*, and SLC1-1 Transformant #42 (nmol /50 seeds \pm SD)

Line	TAG C# \rightarrow	C ₅₀	C ₅₂	C ₅₄	C ₅₆	C ₅₈	C ₆₀	Total
WT Con (n=5)	nmol \pm SD	5.9 0.3	44.3 3.2	115.3 10.3	163.3 16.3	56.9 7.3	5.9 1.4	391.6 37.3
	mol % \pm SD	1.5 0.1	11.3 0.4	29.5 0.7	41.7 0.4	14.5 0.8	1.5 0.3	100.0
	mol % C ₅₆ -C ₆₀	57.7						
42 (n=2)	nmol \pm SD	3.5 0.1	32.7 0.2	108.1 0.9	194.3 0.4	95.6 1.2	16.6 0.8	450.8 3.5
	mol % \pm SD	0.8 0.01	7.2 0.01	24.0 0.004	43.1 0.3	21.2 0.1	3.7 0.2	100.0
	mol % C ₅₆ -C ₆₀	68.0						

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Table 4

TAG Species Accumulating in T₂ Seeds of Untransformed WT Control *A. thaliana*, and SLC1-1 Transformant #16 (nmol /50 seeds ± SD)

WT Con (n=5)	nmol	5.9	44.3	115.3	163.3	56.9	5.9	391.6
	SD	0.3	3.2	10.3	16.3	7.3	1.4	37.3
	mol %	1.5	11.3	29.5	41.7	14.5	1.5	100.0
	SD	0.1	0.4	0.7	0.4	0.8	0.3	
mol % C₅₆-C₆₀		57.7						
16 (n=2)	nmol	6.5	51.3	144.1	214.9	82.7	10.6	510.1
	SD	0.1	0.3	1.4	2.9	2.0	0.6	7.1
	mol %	1.3	10.1	28.3	42.1	16.2	2.1	100.0
	SD	0.04	0.1	0.1	0.02	0.2	0.1	
mol % C₅₆-C₆₀		60.4						

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Table 5

Eicosenoic (20:1), Erucic (22:1) and Total Very-Long Chain Fatty Acid (VLCFA) Content of T₂ Seed In Untransformed WT Control *A. thaliana* , pBI121 Controls and *SLC1-1* Transgenic Lines (μg / 50 seeds)

Line	20:1	22:1	Total VLCFAs
WT Con SD (n=5)	74.8 6.4	8.3 0.7	102.8 10.1
pBI121 Con SD (n=2)	73.8 2.3	7.0 0.3	96.7 3.4
16	96.4	11.0	132.6
20	118.8	12.4	159.2
23	106.9	11.7	146.4
42	103.6	17.4	150.3
52	110.0	12.6	148.2
54	119.5	11.6	156.8

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Table 6

Proportions of Eicosenoic Acid (20:1), and Total VLCFAs in T₂ Seed of Untransformed WT Controls (u-WT), pBI121 Controls, and Selected SLC1-1 Transgenic Lines of *A. thaliana* (wt % in 50-seed samples)

Line	20:1	All VLCFAs
u-WT Con	20.0	27.6
pBI121 Con	20.5	26.3
42	22.7	33.0
52	24.1	32.5
54	23.6	31.0

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Table 7

Total Lipid Content (μg total FA /100 seeds) and VLCFA Content (μg /100 seeds) in Mature T₃ Seed of pBI121 Controls (pBI121 Con), and Selected SLC1-1 Transgenic Lines of *A. thaliana* (μg / 100 seeds)

Line	Total Lipid Content	VLCFA Content
pBI121 Con a	483.5	119.7
pBI121 Con b	568.5	127.2
pBI121 Con c	519.7	125.1
pBI121 Con d	511.3	122.3
pBI121 Con Avg ± SE (n=4)	520.7 15.3	123.6 1.4
42-1	1137.9	315.5
42-4	851.7	218.6
42-5	984.6	268.0
23-8	1056.1	287.7
52-2	1109.2	307.5
52-5	870.0	253.3
52-6	1039.1	281.6
16-5	1955.3	227.0

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Table 8

Total TAG Content and C₅₈ and C₆₀ TAG Content of Mature T₃ Seed of pBI121 Controls (pBI121 Con), and Selected SLC1-1 Transgenic Lines of *A. thaliana* (nmol / 100-seed samples)

TAG C #→	C ₅₀	C ₅₂	C ₅₄	C ₅₆	C ₅₈	C ₆₀	Total
pBI121 Con	8.5	55.3	130.9	145.3	30.9	nd *	371.0
± SE (n=6)	0.4	2.6	7.8	9.0	2.7		21.6
16-5	12.4	88.2	214.7	251.6	70.5	5.6	642.9
23-8	17.7	130.8	333.6	409.0	106.8	8.0	1005.9
42-4	11.4	90.7	259.6	366.4	127.7	14.3	870.0
52-6	15.2	106.1	252.1	322.7	85.5	6.0	787.7

* nd = not detected

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Table 9

Proportion of 20:1 at the *sn*-2 Position of TAGs (wt % *sn*-2 20:1) and Proportion of Total 20:1 Found at the *sn*-2 Position of TAGs (wt % of total 20:1 at *sn*-2 position) in Mature T₃ Seed of pBI121 Controls (pBI121 Con), and Selected SLC1-1 Transgenic Lines of *A. thaliana* (wt % / 100-seed samples)

Line	wt % <i>sn</i> -2 20:1	wt % of Total 20:1 at <i>sn</i> -2 position *
pBI121 Con a	1.7	3.6
pBI121 Con b	0.6	1.1
pBI121 Con c	0.5	0.9
pBI121 Con d	1.6	3.0
16-5	4.2	16.3
42-1	5.1	8.5
42-4	7.9	12.8
42-5	5.3	8.7
23-8	7.5	12.0
52-2	6.2	10.0
52-5	5.8	9.7
52-6	7.5	12.0

* % of Total 20:1 in *sn*-2 position = (% in *sn*-2 / [3 x % Total 20:1]) x 100

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B. napus and *B. carinata* *SLC1-1* Transformant Seed Lipid Analyses:

Several *B. napus* cv. Hero, cv. Reston, and *B. carinata* *SLC1-1* *T₂* transformant seed lines exhibited increased oil content (Table 10) and increased erucic acid content, expressed as µg/ mg DW, or as µg/seed (Table 11). In *B. napus* cvs. Hero and Reston, seeds of several *SLC1-1* transgenic lines exhibited increased proportions of erucic acid (Table 12), compared to the corresponding levels in 10 untransformed control plants. Single seed analyses from a selected average untransformed Hero plant (plant 4) and an *SLC1-1* transformant line with a promising high oil yield and high erucic acid phenotype (Line 8, plant 6) indicated a distribution of these traits suggestive of a seed 15 population segregating in a typical Mendelian fashion for a single insert (Table 13). Some seeds of Hero Line 8 plant 6, exhibited probable homozygous WT (e.g. seed 8-6I) or homozygous *SLC1-1* (e.g. seeds 8-6K and 8-6H) phenotypes for all three traits (high oil yield, increased erucic acid 20 content, increased proportions of erucic acid), while others displayed probable heterozygous WT/*SLC1-1* profiles with intermediate values for these three traits (e.g. seed 8-6B).

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Table 10

Oil Yield (% Dry Weight) in T_2 Seeds of Untransformed Control (Con) and Selected SLC1-1 Transgenic Lines of *B. napus* cvs. HERO and RESTON, and in *B. carinata* breeding line C90-1163 (\pm SE where applicable).

Line	Oil Yield (% DW)
<i>B. napus</i> cv HERO	
Con	40.1 \pm 1.7
5-1	46.7
5-4	48.7
7-3	45.3
7-6	46.4
7-9	44.9
8-4	45.9
8-6	50.9
8-7	44.9
8-10	45.1
<i>B. napus</i> cv RESTON	
Con	33.4 \pm 2.2
1-7	41.9
1-8	40.5
2-8	42.1
2-9	42.2
<i>Brassica carinata</i> line C90-1163	
Con	35.9 \pm 1.1
<i>B. car</i> 10-1-7	42.8
<i>B. car</i> 2-3-6	39.9

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Table 11

Erucic Acid Content (expressed as $\mu\text{g} / \text{mg DW}$ or $\mu\text{g} / \text{seed}$) in Mature T_2 Seeds of Untransformed Control (Con) and Selected *SLC1-1* Transgenic Lines of *B. napus* cv. HERO, and in *B. carinata* breeding line C90-1163 (\pm SE for Controls).

Line	22:1 ($\mu\text{g} / \text{mg DW}$)	22:1 ($\mu\text{g} / \text{seed}$)
<i>Brassica carinata</i> line C90-1163		
Con	156.4 \pm 5.6	—
10-1-7	180.4	—
<i>B. napus</i> cv HERO		
Con	195.5 \pm 11.7	596.7 \pm 40.6
5-1	247.9	900.6
5-4	249.4	818.8
7-3	236.1	—
7-6	244.8	912
7-9	229.2	857.6
8-4	235.7	923.2
8-6	270.9	1020.3
8-7	238.5	888.3
8-10	232.7	900.4
3-1	—	—

— not determined

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Table 12

Proportions of Erucic Acid (expressed as wt %) in Mature T₂ Seeds of Untransformed Control (Con) and Selected SLC1-1 Transgenic Lines of *B. napus* cvs. HERO and RESTON (\pm SE for Controls).

Line	wt % 22:1
<i>B. napus</i> cv HERO	
Con	48.6 \pm 0.6
5-1	53.1
5-4	—
7-3	52.1
7-6	52.8
7-9	—
8-4	51.4
8-6	53.3
8-7	51.8
8-10	53.6
3-1	58.3
<i>B. napus</i> cv RESTON	
Con	34.7 \pm 0.2
1-10	36.4
1-7	35.8
1-8	37.4
2-3	36.6
2-7	41.1

— not determined

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Table 13

Variation in Lipid Content (expressed as μg total fatty acids /seed) and Erucic Acid Content (expressed as μg 22:1 /seed or as wt% 22:1) in Mature T_2 Single Seeds of Untransformed Control plant 4 and SLC1-1 Transgenic Line-8 plant 6 of *B. napus* cv. HERO (\pm SE for Averages, AVG).

Line /Seed	μg FAs / seed	μg 22:1 / seed	Wt % 22:1
AVG Con 4	1076.7 \pm 61.5	507.1 \pm 33.7	46.9 \pm 0.8
AVG-8 6	1441.7 \pm 67.3	735.4 \pm 36.5	51.0 \pm 0.6
8 6G	1324.8	710.8	54.1
8 6H	1704.3	877.1	52.5
8 6I	1175.4	557.3	47.4
8 6J	1206.8	629.4	52.2
8 6K	1694.7	911.1	53.8
8 6A	1351.6	658.6	48.7
8 6B	1304.5	670.6	51.4
8 6C	1221.1	639.1	52.3
8 6D	1449.0	714.3	49.3
8 6E	1678.2	844.6	50.3
8 6F	1748.0	876.8	50.2

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There were measurable increases in the proportions of erucic acid and total VLCFAs at the *sn*-2 position in several transformant lines of Hero (Table 14). The effect of the yeast transgene on increasing the *sn*-2 erucic acid 5 content in *B. napus* was somewhat less dramatic than its ability to change the *sn*-2 eicosenoic acid content in *A. thaliana* (c.f. Table 9). However, this is perhaps, not unexpected, based on the relative specificity of the *S. cerevisiae* *sn*-2 acyltransferase for eicosenoyl- vs erucoyl-10 CoA (c.f. Table 1).

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Table 14

sn-2 Erucic Acid and VLCFA Content in Mature T₁ Seeds of Untransformed Control and Selected SLC1-1 Transgenic Lines of *B. napus* cv. HERO.

Line/Seed	<i>sn-2</i> 22:1	<i>sn-2</i> VLCFAs
Hero Control	1.5	3
Hero 8-6	2.8	4.6
Hero 8-6 G (single seed)	3.6	4.44
Hero 3-1	4.12	4.12 *
Hero 8-10	2.22	3.7

* Erucic acid (22:1) is the only *sn-2* VLCFA detected.

Analyses of TAG species composition by GC, indicated that several SLC1-1 transformant lines of Hero had increased proportions of C₆₂ TAGs, and to a lesser extent, 5 C₆₄ and C₆₆ TAGs (Table 15). The proportions of C₆₂ - C₆₆ TAGs containing 2 or more C₂₂ fatty acids, was dramatically increased in Hero SLC1-1 transgenics (Table 15), primarily at the expense of TAGs containing two (C₅₆) or three (C₅₄) C₁₈ fatty acids (data not shown). A similar increase in the 10 proportion of C₆₂ TAGs was observed in some *B. napus* cv. Reston SLC1-1 transgenic lines (Table 15).

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Table 15

Proportions of C₆₂, C₆₄ and C₆₆ TAGs (moi %) in Mature T₂ Seeds of Untransformed Control (Con) and Selected SLC1-1 Transgenic Lines of *B. napus* cvs. HERO and RESTON (\pm SE for Controls).

Line	C ₆₂	C ₆₄	C ₆₆	Total C ₆₂ - C ₆₆
Control	36.72 \pm 1.42	1.32 \pm 0.02	0.10 \pm 0.01	38.14 \pm 1.45
Hero 5-2	51.44	1.81	0.12	53.37
Hero 5-4	48.92	1.95	0.25	51.12
Hero 5-10	56.48	1.46	0.08	58.02
Hero 7-1	57.25	2.19	0.14	59.58
Hero 7-5	55.61	1.98	0.09	57.68
Hero 8-4	44.76	2.14	0.25	47.16
Hero 8-6	53.35	2.22	0.22	55.79
Reston				
Control	18.32	0.94	0.06	19.32
1-8	23.88	1.06	0.07	25.01
2-7	31.67	1.42	0.11	33.20

Analyses of typical control and SLC1-1 *B. napus* cv. Hero transgenics with respect to the seed-to-seed variation in proportions of C₆₂ TAGs, indicated that the SLC1-1 T₂ 5 seed population was segregating, but that many of the single seeds had considerably higher proportions of C₆₂ TAGs than any of the untransformed controls (Table 16).

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Table 16

Single Seed Analyses for Proportions of C₆₂ TAGs (mol %) in Mature T₂ Seeds of Untransformed Control (Con) and SLC1-1 Transgenic Lines of *B. napus* cv. HERO (± SE for averages, AVG).

Line /Seed	C ₆₂ TAGs
Hero Con	
4d	38.54
4e	40.29
4b	36.88
4f	38.81
4g	30.05
4j	35.95
4h	42.84
4l	40.81
4k	43.28
Hero Con AVG	38.6 ± 1.35
Hero 8-6	
8-6 d	36.36
8-6a	47.63
8-6b	54.06
8-6c	54.81
8-6f	44.4
8-6g	56.27
8-6h	53.11
8-6l	42.19
8-6j	51.44
8-6k	58.4
Hero 8-6 AVG	51.35 ± 1.82

Estimates of oil yield increases in SLC1-1 transgenic lines relative to controls, were directly correlated whether expressed on a "per mg dry weight" basis or on a "per seed" basis (Fig. 5), as were estimates of relative oil content by a non-destructive ¹H-NMR method (Fig. 6). Indeed, the NMR results for increased oil yield were also positively correlated with increased seed weights in the SLC1-1 transgenics (Fig. 7), and indicated that contributions to

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increased seed dry weight were directly attributable to increased oil, with negligible contribution from seed water (absence of broad water resonance between the CH_2 OCO- and CHOCO- chemical shifts). Typical 1H -NMR responses from 35-5 seed samples of control and "high oil" *SLC1-1* transgenic lines of *B. napus* cv. Hero and *B. carinata*, are depicted in Table 17.

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Table 17

¹H-NMR Integral Response for Resonances Assigned to Liquidlike Oil (as described by Rutar, 1989) in Mature T₂ Seeds of Untransformed Controls and Selected SLC1-1 Transgenic Lines of *B. napus* cv. HERO and *B. carinata* breeding line C90-1163. (35-seed samples; Responses relative to Control integration, set at 1.000)

Line	NMR Integral Response
<i>B. napus</i> cv HERO	
Control	1.0000
Hero 5-1	1.5175
Hero 7-3	1.2721
Hero 7-6	1.3875
Hero 7-9	1.3245
Hero 8-4	1.5667
Hero 8-6	1.5297
Hero 8-7	1.4825
Hero 8-10	1.6302
<i>B. carinata</i> cv. C90-1163	
Control	1.0000
<i>B. car.</i> 10-1-7	1.5977
<i>B. car.</i> 2-3-6	1.7548

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Some *B. napus* cv. Westar (Canola) *SLC1-1* T_2 transformant seed lines showed increases in the relative proportion of oleic acid, and concomitant decreases in the 5 relative proportions of polyunsaturated fatty acids (18:2 and 18:3) (Table 18). This is in contrast to the predicted effect as cited in the University of Kentucky patent application. Thus, the proportions of mono-unsaturated fatty acids can be increased in edible oils, by expression 10 of *SLC1-1*. Furthermore, the proportions of saturated very long chain fatty acids in these Canola lines were significantly increased (Table 18).

15

Table 18
Oleic, Linoleic, Linolenic and Saturated VLCFA Compositions of Untransformed Control and Selected *SLC1-1* Transgenic Lines of *B. napus* cv. WESTAR (n=2 or 3)

Line	Oleic 18:1c9	Linoleic 18:2 c9,12	Linolenic 18:3 c9,12,15	Eicosanoic 20:0	Behenic 22:0	Lignoceric 24:0
<i>B. napus</i> cv WESTAR						
Control	61.03	17.55	11.07	0.55	0.31	0.27
WS-13	70.03	14.80	3.41	0.76	0.49	0.56
WS-15	71.92	12.33	3.71	0.78	0.53	0.48
WS-16	71.06	12.29	3.87	0.97	0.59	0.56
WS- 15a	72.71	9.69	3.09	0.94	0.65	0.68

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LPAT Analyses of Transformant Lines:

Samples of *B. napus* cv. Westar and *B. napus* cv. Argentine *SLC1-1* T₁ transformant lines exhibited increased 5 leaf 18:1-CoA:LPAT activities in rapidly-expanding leaf homogenate preparations compared to those from untransformed control plants (Table 19).

Developing seed LPAT analyses in untransformed control and *SLC1-1* transgenics of *B. napus* cv. Hero and *B. carinata* 10 indicated that both 18:1-CoA:LPAT and 22:1-CoA:LPAT (Table 19) specific activities were dramatically increased in the *SLC1-1* transgenics.

Developing seed LPAT analyses of untransformed control and *SLC1-1* transgenics of *A. thaliana* indicated that 20:1-15 CoA:LPAT activity was increased in several *SLC1-1* transgenics (Table 19).

Thus, in this deposition we provide, for the first time, direct evidence that the yeast *SLC1-1* gene product encodes an enzyme which possesses *sn*-2 acyltransferase 20 activity, and which can exhibit LPAT (EC 2.3.1.51) activity *in vitro*.

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Table 19

Relative LPAT Activities in Homogenates Prepared from T₁, Leaf and T₂ or T₃ Developing Seed of Untransformed Controls and Selected SLC1-1 Transgenic Lines of 5 *B. napus* cvs. WESTAR, ARGENTINE and HERO, *B. carinata* cv. C90-1163, and *A. thaliana* cv. COLUMBIA. All assays conducted as described in experimental section.

Line	Tissue Assayed	LPAT Activity Assayed	DPM ¹⁴ C acyl-CoA incorporated into PA / μ g pr
<i>B. napus</i> Westar	T ₁ , Leaves	18:1-CoA	
Control			307
WS 2-5			1008
WS 3-8			617
WS 6-7			1428
<i>B. napus</i> Arg.	T ₁ , Leaves	18:1-CoA	
Control			350
Arg 2-8			996
Arg 3-3			1557
<i>B. napus</i> Hero	T ₂ Dev. Seeds	18:1-CoA	
Control			580
Hero 3-1			3470
Hero 7-6			2035
Hero 8-6			1370
<i>B. car.</i> C90-1163	T ₂ Dev. Seeds	18:1-CoA	
Control			720
<i>B. car.</i> 10-1-7			1125
<i>B. napus</i> Hero	T ₂ Dev. Seeds	22:1-CoA	
Control			6.4
Hero 3-1			68.3
Hero 7-6			53.4
Hero 8-6			20.2
<i>A. thaliana</i>	T ₃ Dev. Seeds	20:1-CoA	
WT u-Control			238
42-1			270
42-4			380
42-5			503

Genetic Analyses of SLC1-1 Transformants:

10

PCR and Southern analyses data for the transgenic plant lines cited in this deposition are summarized in Table 20.

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TABLE 20
 Summary of PCR and Southern data
 for *SLC1-1* T_2 transgenic plant lines (nd = not determined)

Oilseed	Transformant # (T_2 line)	PCR	Southern	Insert (Copy) #
<i>A. thaliana</i> cv. COLUMBIA	16	+	+	single
	20	+	+	single
	23	+	+	multiple
	42	+	+	multiple
	52	+	+	multiple
	54	+	+	multiple
<i>B. napus</i> cv. WESTAR	2	+	+	multiple
	3	+	+	multiple
	6	+	+	multiple
	13	nd	+	single
	15	nd	+	multiple
	16	nd	+	multiple
<i>B. napus</i> cv. ARGENTINE	2	+	+	multiple
	3	+	+	multiple
<i>B. napus</i> cv. HERO	5	+	+	single
	7	+	+	single
	8	+	+	single
	3	+	+	single
<i>B. carinata</i> cv. C90-1163	10	+	+	single
	2	+	+	multiple

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To follow the segregation pattern in the T₂ generation of *A. thaliana* *SLC1-1* transformants, seeds from transgenic lines (e.g. lines 16, 20) which showed increases in oil content and amounts of long (C₁₈) and very long chain fatty acids (C₂₀ and C₂₂) were sterilized and germinated on selective medium (50 mg/L kanamycin). Both lines showed the same 3:1 (kanamycin resistant:kanamycin sensitive) segregation pattern which indicates that the marker segregates as one Mendelian locus. Southern hybridization analyses (Southern, 1975) confirmed the presence of a single T-DNA insert per genome. In lines 23, 42, 52 and 54, Southern hybridization analyses suggest that all of the lines have more than one T-DNA insert per genome.

Northern hybridization analyses of seeds at mid-development isolated from siliques of *A. thaliana* lines 16, 20, 23, 42, 52 and 54 confirmed the expression of *SLC1-1* gene in all lines tested, with the highest level of expression in line 42.

Southern analysis of genomic DNA which was isolated from *B. napus* cv. Westar transgenic lines (2, 3, 6, 13, 15, 16) revealed that only line 13 had a single insert. Both *B. napus* cv. Argentine *SLC1-1* transgenic lines (2, 3) had multiple inserts. *B. napus* cv. Hero transgenic lines (3, 5, 7, 8) and *B. carinata* transgenic line 10, each had a single insert, while *B. carinata* line 2 had multiple T-DNA inserts per genome.

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SEQUENCE LISTING

(1) GENERAL INFORMATION:

(i) APPLICANT:

(A) NAME: National Research Council of Canada
(B) STREET: 1200 Montreal Road
(C) CITY: Ottawa
(D) STATE: Ontario
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(D) STATE: Saskatchewan
(E) COUNTRY: Canada
(F) POSTAL CODE (ZIP): S7H 2Z6

(A) NAME: Taylor, David C.
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(C) CITY: Saskatoon
(D) STATE: Saskatchewan
(E) COUNTRY: Canada
(F) POSTAL CODE (ZIP): S7J 4C3

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(B) STREET: 301 1121 C McKercher Drive
(C) CITY: Saskatoon
(D) STATE: Saskatchewan
(E) COUNTRY: Canada
(F) POSTAL CODE (ZIP): S7H 5B8

(A) NAME: MacKenzie, Samuel L.
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(C) CITY: Saskatoon
(D) STATE: Saskatchewan
(E) COUNTRY: Canada
(F) POSTAL CODE (ZIP): S7H 3P9

(A) NAME: Keller, Wilfred A.
(B) STREET: 234 Emmeline Road
(C) CITY: Saskatoon
(D) STATE: Saskatchewan
(E) COUNTRY: Canada
(F) POSTAL CODE (ZIP): S7J 5B6

(ii) TITLE OF INVENTION: MODIFICATION OF PLANT LIPIDS AND SEED OILS
UTILIZING YEAST SLC GENES

(iii) NUMBER OF SEQUENCES: 6

(iv) COMPUTER READABLE FORM:

(A) MEDIUM TYPE: Floppy disk
(B) COMPUTER: IBM PC compatible
(C) OPERATING SYSTEM: PC-DOS/MS-DOS
(D) SOFTWARE: PatentIn Release #1.0, Version #1.30 (EPO)

(2) INFORMATION FOR SEQ ID NO: 1:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 947 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

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(vi) ORIGINAL SOURCE:
 (A) ORGANISM: *Saccharomyces cerevisiae*

(ix) FEATURE:
 (A) NAME/KEY: CDS
 (B) LOCATION: 1..909

(xi) SEQUENCE DESCRIPTION: SEQ ID NO: 1:

ATG AGT GTG ATA GGT AGG TTC TTG TAT TAC TTG AGG TCC GTG TTG GTC Met Ser Val Ile Gly Arg Phe Leu Tyr Tyr Leu Arg Ser Val Leu Val 1 5 10 15	48
GTA CTG GCG CTT GCA GGC TGT GGC TTT TAC GGT GTA ATC GCC TCT ATC Val Leu Ala Leu Ala Gly Cys Gly Phe Tyr Gly Val Ile Ala Ser Ile 20 25 30	96
CTT TGC ACG TTA ATC GGT AAG CAA CAT TTG GCT CTG TGG ATT ACT GCG Leu Cys Thr Leu Ile Gly Lys Gln His Leu Ala Leu Trp Ile Thr Ala 35 40 45	144
CGT TGT TTT TAC CAT GTC ATG AAA TTG ATG CTT GGC CTT GAC GTC AAG Arg Cys Phe Tyr His Val Met Lys Leu Met Leu Gly Leu Asp Val Lys 50 55 60	192
GTC GTT GGC GAG GAG AAT TTG GCC AAG AAG CCA TAT ATT ATG ATT GCC Val Val Gly Glu Asn Leu Ala Lys Lys Pro Tyr Ile Met Ile Ala 65 70 75 80	240
AAT CAC CAA TCC ACC TTG GAT ATC TTC ATG TTA GGT AGG ATT TTC CCC Asn His Gln Ser Thr Leu Asp Ile Phe Met Leu Gly Arg Ile Phe Pro 85 90 95	288
CCT GGT TGC ACA GTT ACT GCC AAG AAG TCT TTG AAA TAC GTC CCC TTT Pro Gly Cys Thr Val Thr Ala Lys Ser Leu Lys Tyr Val Pro Phe 100 105 110	336
CTG GGT TGG TTC ATG GCT TTG AGT GGT ACA TAT TTC TTA GAC AGA TCT Leu Gly Trp Phe Met Ala Leu Ser Gly Thr Tyr Phe Leu Asp Arg Ser 115 120 125	384
AAA AGG CAA GAA GCC ATT GAC ACC TTG AAT AAA GGT TTA GAA AAT GTT Lys Arg Gln Glu Ala Ile Asp Thr Leu Asn Lys Gly Leu Glu Asn Val 130 135 140	432
AAG AAA AAC AAG CGT GCT CTA TGG GTT TTT CCT GAG GGT ACC AGG TCT Lys Lys Asn Lys Arg Ala Leu Trp Val Phe Pro Glu Gly Thr Arg Ser 145 150 155 160	480
TAC ACG AGT GAG CTG ACA ATG TTG CCT TTC AAG AAG GGT GCT TTC CAT Tyr Thr Ser Glu Leu Thr Met Leu Pro Phe Lys Lys Gly Ala Phe His 165 170 175	528
TTG GCA CAA CAG GGT AAG ATC CCC ATT GTT CCA GTG GTT GTT TCC AAT Leu Ala Gln Gln Gly Lys Ile Pro Ile Val Pro Val Val Val Ser Asn 180 185 190	576
ACC AGT ACT TTA GTA AGT CCT AAA TAT GGG GTC TTC AAC AGA GGC TGT Thr Ser Thr Leu Val Ser Pro Lys Tyr Gly Val Phe Asn Arg Gly Cys 195 200 205	624
ATG ATT GTT AGA ATT TTA AAA CCT ATT TCA ACC GAG AAC TTA ACA AAG Met Ile Val Arg Ile Leu Lys Pro Ile Ser Thr Glu Asn Leu Thr Lys 210 215 220	672
GAC AAA ATT GGT GAA TTT GCT GAA AAA GTT AGA GAT CAA ATG GTT GAC Asp Lys Ile Gly Glu Phe Ala Glu Lys Val Arg Asp Gln Met Val Asp 225 230 235 240	720
ACT TTG AAG GAG ATT GGC TAC TCT CCC GCC ATC AAC GAT ACA ACC CTC Thr Leu Lys Glu Ile Gly Tyr Ser Pro Ala Ile Asn Asp Thr Leu	768

245	250	255	
CCA CCA CAA GCT ATT GAG TAT GCC GCT CTT CAA CAT GAC AAG AAA GTG			816
Pro Pro Gln Ala Ile Glu Tyr Ala Ala Leu Gln His Asp Lys Lys Val			
260	265	270	
AAC AAG AAA ATC AAG AAT GAG CCT GTG CCT TCT GTC AGC ATT AGC AAC			864
Asn Lys Lys Ile Lys Asn Glu Pro Val Pro Ser Val Ser Ile Ser Asn			
275	280	285	
GAT GTC AAT ACC CAT AAC GAA GGT TCA TCT GTA AAA AAG ATG CAT			909
Asp Val Asn Thr His Asn Glu Gly Ser Ser Val Lys Lys Met His			
290	295	300	
TAAGCCACCA CCACATTTT AGAGTAGTAT ATAGACCC			947

(2) INFORMATION FOR SEQ ID NO: 2:

(i) SEQUENCE CHARACTERISTICS:
 (A) LENGTH: 303 amino acids
 (B) TYPE: amino acid
 (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein
 (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 2:

Met Ser Val Ile Gly Arg Phe Leu Tyr Tyr Leu Arg Ser Val Leu Val			
1	5	10	15
Val Leu Ala Leu Ala Gly Cys Gly Phe Tyr Gly Val Ile Ala Ser Ile			
20	25	30	
Leu Cys Thr Leu Ile Gly Lys Gln His Leu Ala Leu Trp Ile Thr Ala			
35	40	45	
Arg Cys Phe Tyr His Val Met Lys Leu Met Leu Gly Leu Asp Val Lys			
50	55	60	
Val Val Gly Glu Glu Asn Leu Ala Lys Lys Pro Tyr Ile Met Ile Ala			
65	70	75	80
Asn His Gln Ser Thr Leu Asp Ile Phe Met Leu Gly Arg Ile Phe Pro			
85	90	95	
Pro Gly Cys Thr Val Thr Ala Lys Lys Ser Leu Lys Tyr Val Pro Phe			
100	105	110	
Leu Gly Trp Phe Met Ala Leu Ser Gly Thr Tyr Phe Leu Asp Arg Ser			
115	120	125	
Lys Arg Gln Glu Ala Ile Asp Thr Leu Asn Lys Gly Leu Glu Asn Val			
130	135	140	
Lys Lys Asn Lys Arg Ala Leu Trp Val Phe Pro Glu Gly Thr Arg Ser			
145	150	155	160
Tyr Thr Ser Glu Leu Thr Met Leu Pro Phe Lys Lys Gly Ala Phe His			
165	170	175	
Leu Ala Gln Gln Gly Lys Ile Pro Ile Val Pro Val Val Ser Asn			
180	185	190	
Thr Ser Thr Leu Val Ser Pro Lys Tyr Gly Val Phe Asn Arg Gly Cys			
195	200	205	
Met Ile Val Arg Ile Leu Lys Pro Ile Ser Thr Glu Asn Leu Thr Lys			
210	215	220	
Asp Lys Ile Gly Glu Phe Ala Glu Lys Val Arg Asp Gln Met Val Asp			
225	230	235	240
Thr Leu Lys Glu Ile Gly Tyr Ser Pro Ala Ile Asn Asp Thr Thr Leu			

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245	250	255
Pro Pro Gln Ala Ile Glu Tyr Ala Ala	Leu Gln His Asp Lys Lys Val	
260	265	270
Asn Lys Lys Ile Lys Asn Glu Pro Val Pro Ser Val Ser Ile Ser Asn		
275	280	285
Asp Val Asn Thr His Asn Glu Gly Ser Ser Val Lys Lys Met His		
290	295	300

(2) INFORMATION FOR SEQ ID NO: 3:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 947 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(ix) FEATURE:
(A) NAME/KEY: CDS
(B) LOCATION: 1..909

(xi) SEQUENCE DESCRIPTION: SEQ ID NO: 3.

ATG AGT GTG ATA GGT AGG TTC TTG TAT TAC TTG AGG TCC GTG TTG GTC Met Ser Val Ile Gly Arg Phe Leu Tyr Tyr Leu Arg Ser Val Leu Val 1 5 10 15	48
GTA CTG GCG CTT GCA GGC TGT GGC TTT TAC GGT GTA ATC GCC TCT ATC Val Leu Ala Leu Ala Gly Cys Gly Phe Tyr Gly Val Ile Ala Ser Ile 20 25 30	96
CTT TGC ACG TTA ATC GGT AAG CAA CAT TTG GCT CAG TGG ATT ACT GCG Leu Cys Thr Leu Ile Gly Lys Gln His Leu Ala Gln Trp Ile Thr Ala 35 40 45	144
CGT TGT TTT TAC CAT GTC ATG AAA TTG ATG CTT GGC CTT GAC GTC AAG Arg Cys Phe Tyr His Val Met Lys Leu Met Leu Gly Leu Asp Val Lys 50 55 60	192
GTC GTT GGC GAG GAG AAT TTG GCC AAG AAG CCA TAT ATT ATG ATT GCC Val Val Gly Glu Asn Leu Ala Lys Lys Pro Tyr Ile Met Ile Ala 65 70 75 80	240
AAT CAC CAA TCC ACC TTG GAT ATC TTC ATG TTA GGT AGG ATT TTC CCC Asn His Gln Ser Thr Leu Asp Ile Phe Met Leu Gly Arg Ile Phe Pro 85 90 95	288
CCT GGT TGC ACA GTT ACT GCC AAG AAG TCT TTG AAA TAC GTC CCC TTT Pro Gly Cys Thr Val Thr Ala Lys Lys Ser Leu Lys Tyr Val Pro Phe 100 105 110	336
CTG GGT TGG TTC ATG GCT TTG AGT GGT ACA TAT TTC TTA GAC AGA TCT Leu Gly Trp Phe Met Ala Leu Ser Gly Thr Tyr Phe Leu Asp Arg Ser 115 120 125	384
AAA AGG CAA GAA GCC ATT GAC ACC TTG AAT AAA GGT TTA GAA AAT GTT Lys Arg Gln Glu Ala Ile Asp Thr Leu Asn Lys Gly Leu Glu Asn Val 130 135 140	432
AAG AAA AAC AAG CGT GCT CTA TGG GTT TTT CCT GAG GGT ACC AGG TCT Lys Lys Asn Lys Arg Ala Leu Trp Val Phe Pro Glu Gly Thr Arg Ser 145 150 155 160	480
TAC ACG AGT GAG CTG ACA ATG TTG CCT TTC AAG AAG GGT GCT TTC CAT Tyr Thr Ser Glu Leu Thr Met Leu Pro Phe Lys Lys Gly Ala Phe His 165 170 175	528

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TTG GCA CAA CAG GGT AAG ATC CCC ATT GTT CCA GTG GTT GTT TCC AAT Leu Ala Gln Gln Gly Lys Ile Pro Ile Val Pro Val Val Val Ser Asn 180 185 190	576
ACC AGT ACT TTA GTA AGT CCT AAA TAT GGG GTC TTC AAC AGA GGC TGT Thr Ser Thr Leu Val Ser Pro Lys Tyr Gly Val Phe Asn Arg Gly Cys 195 200 205	624
ATG ATT GTT AGA ATT TTA AAA CCT ATT TCA ACC GAG AAC TTA ACA AAG Met Ile Val Arg Ile Leu Lys Pro Ile Ser Thr Glu Asn Leu Thr Lys 210 215 220	672
GAC AAA ATT GGT GAA TTT GCT GAA AAA GTT AGA GAT CAA ATG GTT GAC Asp Lys Ile Gly Glu Phe Ala Glu Lys Val Arg Asp Gln Met Val Asp 225 230 235 240	720
ACT TTG AAG GAG ATT GGC TAC TCT CCC GCC ATC AAC GAT ACA ACC CTC Thr Leu Lys Glu Ile Gly Tyr Ser Pro Ala Ile Asn Asp Thr Thr Leu 245 250 255	768
CCA CCA CAA GCT ATT GAG TAT GCC GCT CTT CAA CAT GAC AAG AAA GTG Pro Pro Gln Ala Ile Glu Tyr Ala Ala Leu Gln His Asp Lys Lys Val 260 265 270	816
AAC AAG AAA ATC AAG AAT GAG CCT GTG CCT TCT GTC AGC ATT AGC AAC Asn Lys Lys Ile Lys Asn Glu Pro Val Pro Ser Val Ser Ile Ser Asn 275 280 285	864
GAT GTC AAT ACC CAT AAC GAA GGT TCA TCT GTA AAA AAG ATG CAT Asp Val Asn Thr His Asn Glu Gly Ser Ser Val Lys Lys Met His 290 295 300	909
TAAGCCACCA CCACATTTT AGAGTAGTAT ATAGACCC	947

(2) INFORMATION FOR SEQ ID NO: 4:

(i) SEQUENCE CHARACTERISTICS:
 (A) LENGTH: 303 amino acids
 (B) TYPE: amino acid
 (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein
 (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 4:

Met Ser Val Ile Gly Arg Phe Leu Tyr Tyr Leu Arg Ser Val Leu Val 1 5 10 15
Val Leu Ala Leu Ala Gly Cys Gly Phe Tyr Gly Val Ile Ala Ser Ile 20 25 30
Leu Cys Thr Leu Ile Gly Lys Gln His Leu Ala Gln Trp Ile Thr Ala 35 40 45
Arg Cys Phe Tyr His Val Met Lys Leu Met Leu Gly Leu Asp Val Lys 50 55 60
Val Val Gly Glu Glu Asn Leu Ala Lys Lys Pro Tyr Ile Met Ile Ala 65 70 75 80
Asn His Gln Ser Thr Leu Asp Ile Phe Met Leu Gly Arg Ile Phe Pro 85 90 95
Pro Gly Cys Thr Val Thr Ala Lys Lys Ser Leu Lys Tyr Val Pro Phe 100 105 110
Leu Gly Trp Phe Met Ala Leu Ser Gly Thr Tyr Phe Leu Asp Arg Ser 115 120 125
Lys Arg Gln Glu Ala Ile Asp Thr Leu Asn Lys Gly Leu Glu Asn Val 130 135 140

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Lys Lys Asn Lys Arg Ala Leu Trp Val Phe Pro Glu Gly Thr Arg Ser
 145 150 155 160
 Tyr Thr Ser Glu Leu Thr Met Leu Pro Phe Lys Lys Gly Ala Phe His
 165 170 175
 Leu Ala Gln Gln Gly Lys Ile Pro Ile Val Pro Val Val Val Ser Asn
 180 185 190
 Thr Ser Thr Leu Val Ser Pro Lys Tyr Gly Val Phe Asn Arg Gly Cys
 195 200 205
 Met Ile Val Arg Ile Leu Lys Pro Ile Ser Thr Glu Asn Leu Thr Lys
 210 215 220
 Asp Lys Ile Gly Glu Phe Ala Glu Lys Val Arg Asp Gln Met Val Asp
 225 230 235 240
 Thr Leu Lys Glu Ile Gly Tyr Ser Pro Ala Ile Asn Asp Thr Thr Leu
 245 250 255
 Pro Pro Gln Ala Ile Glu Tyr Ala Ala Leu Gln His Asp Lys Lys Val
 260 265 270
 Asn Lys Lys Ile Lys Asn Glu Pro Val Pro Ser Val Ser Ile Ser Asn
 275 280 285
 Asp Val Asn Thr His Asn Glu Gly Ser Ser Val Lys Lys Met His
 290 295 300

(2) INFORMATION FOR SEQ ID NO: 5:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 32 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

- (ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO: 5:

AGAGAGAGGG ATCCATGAGT GTGATAGGTA GG

32

(2) INFORMATION FOR SEQ ID NO: 6:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 33 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

- (ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO: 6:

GAGGAAGAAG GATCCGGGTC TATATACTAC TCT

33

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References of Interest to the Present Invention

1. Alexander, D.E., Silvela, L.S., Collins, F.I. and Rodgers, R.C. (1967) Analysis of oil content of maize by wide-line NMR. *J. Am. Oil Chem. Soc.* 44: 555-558.
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3. Bechtold, N., Ellis, J., and Pelletier, G. (1993) *In planta Agrobacterium-mediated gene transfer by infiltration of adult *Arabidopsis thaliana* plants*. *C R Acad Sci Paris, Sciences de la vie/Life sciences* 316: 1194-1199.
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7. Coleman, J. (1992) Characterization of the *Escherichia coli* gene for 1-acyl-*sn*-glycerol-3-phosphate acyltransferase (*plsC*). *Mol. Gen. Genet.* 232: 295-303.

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8. Datla, R., Hammerlindl, J.K., Panchuk, B., Pelcher, L.E. and Keller, W.A. (1992) Modified binary plant transformation vectors with the wild-type gene encoding NPTII. *Gene*, 211: 383-384.
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Patents of Interest to the Current Invention

1. Calgene, Inc. (Patent Applicant); Inventors: Davies, H.M., Hawkins, D., Nelsen, J., Lassner, M.; PCT patent publication WO 95/27791. "Plant lysophosphatidic acid acyltransferases."
2. Calgene Inc. has been granted a US patent (WPI Accession No. 91-348069-48; *Biotech Patent News*, 6, 1992) governing the use of anti-sense technology in plant cells.
3. duPont de Nemours and Company (Patent Applicant; Inventors: Lightner, J.E., Okuley, J.J.; PCT patent publication WO 94/11516; Published European patent application EP 0668919. "Genes for microsomal delta-12 fatty acid desaturases and related enzymes from plants."
4. Nickerson Biocem. Ltd. (Patent Assignee); Inventors: Slabas A.R. and Brown, A.P.; PCT patent publication WO 94/13814; European patent publication EP 0673424. "DNA encoding 2-acyltransferases."
5. University of Kentucky Research Foundation (Patent Applicant); Authors: Dickson, R. et al.; unpublished pending US Patent Application Serial No. 434,039. "A technique for specifying the fatty acid at the *sn*-2 position of acylglycerol lipids."

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Claims:

1. A transgenic oilseed plant characterized in that said plant has a genome incorporating an expressible yeast *SLC1-1* or *SLC1* gene.
2. A plant according to claim 1 characterized in that said plant exhibits improved seed oil yield and/or a different seed oil composition compared with a plant of the same type that does not contain said gene.
3. A plant according to claim 1 characterized in that said gene has the nucleotide sequence of SEQ ID NO:1.
4. A plant according to claim 1 characterized in that said gene has the nucleotide sequence of SEQ ID NO: 3.
5. A plant according to claim 1, claim 2, claim 3 or claim 4 characterized in that said plant produces non-edible oils.
6. A plant according to claim 1, claim 2, claim 3 or claim 4 characterized in that said plant produces edible oil.
7. A plant according to claim 1, claim 2, claim 3 or claim 4 characterized in that said plant is *Arabidopsis thaliana* modified to include said gene.
8. A plant according to claim 1, claim 2, claim 3 or claim 4 characterized in that said plant is a member of the *Brassicaceae* modified to include said gene.
9. A plant according to claim 1, claim 2, claim 3 or claim 4 characterized in that said plant is *Brassica napus* modified to include said gene.

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10. A plant according to claim 1, claim 2, claim 3 or claim 4 characterized in that said plant is *Brassica carinata* modified to include said gene.
11. A plant according to claim 1, claim 2, claim 3 or claim 4 characterized in that said plant is selected from the group consisting of borage (*Borago* spp.), canola, castor (*Ricinus communis*), cocoa bean (*Theobroma cacao*), corn (*Zea mays*), cotton (*Gossypium* spp.), *Crambe* spp., *Cuphea* spp., flax (*Linum* spp.), *Lesquerella* and *Limnanthes* spp., linola, nasturtium (*Tropaeolum* spp.), *Oenothera* spp., olive (*Olea* spp.), palm (*Elaeis* spp.), peanut (*Arachis* spp.), rapeseed, safflower (*Carthamus* spp.), soybean (*Glycine* and *Soja* spp.), sunflower (*Helianthus* spp.), tobacco (*Nicotiana* spp.) and *Vernonia* spp.
12. A seed of a transgenic oilseed plant characterized in that said plant has a genome incorporating an expressible yeast *SLC1-1* or *SLC1* gene.
13. A seed according to claim 11 characterized in that said gene has a nucleotide sequence of SEQ ID NO:1.
14. A seed according to claim 11 characterized in that said gene has a nucleotide sequence of SEQ ID NO: 3.
15. A seed according to claim 12, claim 13 or claim 14 characterized in that said seed produces non-edible oils.
16. A seed according to claim 12, claim 13 or claim 14 characterized in that said seed produces edible oil.
17. A seed according to claim 12, claim 13 or claim 14 characterized in that said seed is a seed of *Arabidopsis thaliana* modified to include said gene.

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18. A seed according to claim 12, claim 13 or claim 14 characterized in that said seed is a seed of a member of the *Brassicaceae* modified to include said gene.
19. A seed according to claim 12, claim 13 or claim 14 characterized in that said seed is a seed of *Brassica napus* modified to include said gene.
20. A seed according to claim 12, claim 13 or claim 14 characterized in that said seed is a seed of *Brassica carinata* modified to include said gene.
21. A seed according to claim 12, claim 13 or claim 14 characterized in that said seed is a seed of a plant selected from the group consisting of borage (*Borago* spp.), castor (*Ricinus communis*), cocoa bean (*Theobroma cacao*), corn (*Zea mays*), cotton (*Gossypium* spp.), *Crambe* spp., *Cuphea* spp., flax (*Linum* spp.), *Lesquerella* and *Limnanthes* spp., nasturtium (*Tropaeolum* spp.), *Oenothera* spp., olive (*Olea* spp.), palm (*Elaeis* spp.), peanut (*Arachis* spp.), safflower (*Carthamus* spp.), soybean (*Glycine* and *Soja* spp.), sunflower (*Helianthus* spp.), tobacco (*Nicotiana* spp.) and *Vernonia* spp.
22. Plasmid pSLC1-1/pRD400 (ATCC 97545).
23. *Agrobacterium tumefaciens* strain GV3101 characterized in that said strain has been modified to include a yeast SLC1-1 gene.
24. A method of producing a transgenic oilseed plant, characterized in that an expressible yeast *SLC1-1* or *SLC1* gene is introduced into the genome of said plant.
25. A method according to claim 24 further characterized by down-regulating an indigenous gene that encodes lyso-

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phosphatidic acid acyltransferase already present in the transgenic oilseed plant.

26. A method according to claim 24 further characterized by carrying out a second transformation to introduce a further gene for modifying the properties of the transformed plant.
27. A method according to claim 26 characterized in that said further gene is an hydroxylase gene from castor or *Lesquerella* spp.
28. A method according to claim 24 characterized in that said further comprises crossing said transgenic oilseed plant with a related oilseed transformant already containing an expressible foreign or indigenous transgene affecting oilseed composition, to produce oilseed plants yielding modified fatty acids.
29. A method of producing a transformed oilseed plant with improved tolerance to biotic and abiotic plant stresses, compared with an untransformed plant of the same type, characterized by introducing into the genome of said plant an expressible yeast *SLC1-1* gene or *SLC1* allele.
30. A method of obtaining edible or inedible plant seed oil, characterized by growing an oilseed plant, harvesting seeds of said plant and extracting seed oil from said oilseeds, characterized in that said oilseed plant is a transgenic oilseed plant having a genome incorporating an expressible yeast *SLC1-1* or *SLC1* gene.
31. A method according to claim 28 characterized in that an indigenous gene that encodes lyso-phosphatidic acid acyltransferase already present in said transgenic oilseed plant is down-regulated.

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SLC1-1 Gene

1:	M S V I G R F L Y Y L R S V L V V L A L	21	41
61:	gcaggctgtggctttacggtaatcgccctatccttgcacgttaatcggtaaagcaa	81	101
21:	A G C G F Y G V I A S I L C T L I G K Q	121	141
41:	cattggctctgtggattactgcgcgtgtttaccatgtcatgaaattgatgcttggc	141	161
61:	H L A L W I T A R C F Y H V M K L M L G	181	201
81:	cttgacgtcaaggcgttggcgaggagaattggccaagaagccatataattatgattgcc	201	221
101:	L D V K V V G E E N L A K K P Y I M I A	241	261
121:	aatcaccaatccacccatggatatcttcattgttaggatttccccctggcaca	261	281
141:	N H Q S T L D I F M L G R I F P P G C T	301	321
161:	gttactgccaagaagtctttgaaatacgtcccttctgggttggtcattggctttgagt	321	341
181:	V T A K K S L K Y V P F L G W F M A L S	361	381
201:	ggtacatatttttagacagatctaaaaggcaagaagccattgacacacccatgtaaataaggt	381	401
221:	G T Y F L D R S K R Q E A I D T L N K G	421	441
241:	tttagaaaatgttaagaaaaacaagcgtgctctatgggtttccctgagggtaccaggct	441	461
261:	L E N V K K N K R A L W V F P E G T R S	481	501
281:	501	521	
301:	tacacgagtgagctgacaatgttgccttcaagaagggtgcttccattggcacaacag	541	561
321:	561	581	
341:	ggtaagatccccattgttccagtgggtttccaaataccgtacttttagtaagtccctaaa	601	621
361:	621	641	
381:	641	661	
401:	tatgggtcttcaacagaggctgtatgattttagaaattttaaacctattcaaccgag	681	701
421:	701	721	
441:	aacttaacaaaggacaaaattggtaatttgcgtaaaaagtttagagatcaaattgggtac	721	741
461:	741	761	
481:	actttgaaggagattggctactctccgcacatcaacgatacaaccctccaccacaagct	781	801
501:	801	821	
521:	attgagtatgccgctttcaacatgacaagaaagtgaacaagaaaatcaagaatgagcct	841	861
541:	861	881	
561:	gtgccttctgtcagcattagcaacgtcaataccataacgaagggtcatctgtaaaa	901	921
581:	921	941	
601:	aagatgcattaaagccaccacaccattttagagtagtatataagccc	961	981
621:	981	1001	
641:	1001	1021	
661:	1021	1041	
681:	1041	1061	
701:	1061	1081	
721:	1081	1101	
741:	1101	1121	
761:	1121	1141	
781:	1141	1161	
801:	1161	1181	
821:	1181	1201	
841:	1201	1221	
861:	1221	1241	
881:	1241	1261	
901:	1261	1281	
921:	1281	1301	
941:	1301	1321	
961:	1321	1341	
981:	1341	1361	
1001:	1361	1381	
1021:	1381	1401	
1041:	1401	1421	
1061:	1421	1441	
1081:	1441	1461	
1101:	1461	1481	
1121:	1481	1501	
1141:	1501	1521	
1161:	1521	1541	
1181:	1541	1561	
1201:	1561	1581	
1221:	1581	1601	
1241:	1601	1621	
1261:	1621	1641	
1281:	1641	1661	
1301:	1661	1681	
1321:	1681	1701	
1341:	1701	1721	
1361:	1721	1741	
1381:	1741	1761	
1401:	1761	1781	
1421:	1781	1801	
1441:	1801	1821	
1461:	1821	1841	
1481:	1841	1861	
1501:	1861	1881	
1521:	1881	1901	
1541:	1901	1921	
1561:	1921	1941	
1581:	1941	1961	
1601:	1961	1981	
1621:	1981	2001	
1641:	2001	2021	
1661:	2021	2041	
1681:	2041	2061	
1701:	2061	2081	
1721:	2081	2101	
1741:	2101	2121	
1761:	2121	2141	
1781:	2141	2161	
1801:	2161	2181	
1821:	2181	2201	
1841:	2201	2221	
1861:	2221	2241	
1881:	2241	2261	
1901:	2261	2281	
1921:	2281	2301	
1941:	2301	2321	
1961:	2321	2341	
1981:	2341	2361	
2001:	2361	2381	
2021:	2381	2401	
2041:	2401	2421	
2061:	2421	2441	
2081:	2441	2461	
2101:	2461	2481	
2121:	2481	2501	
2141:	2501	2521	
2161:	2521	2541	
2181:	2541	2561	
2201:	2561	2581	
2221:	2581	2601	
2241:	2601	2621	
2261:	2621	2641	
2281:	2641	2661	
2301:	2661	2681	
2321:	2681	2701	
2341:	2701	2721	
2361:	2721	2741	
2381:	2741	2761	
2401:	2761	2781	
2421:	2781	2801	
2441:	2801	2821	
2461:	2821	2841	
2481:	2841	2861	
2501:	2861	2881	
2521:	2881	2901	
2541:	2901	2921	
2561:	2921	2941	
2581:	2941	2961	
2601:	2961	2981	
2621:	2981	3001	
2641:	3001	3021	
2661:	3021	3041	
2681:	3041	3061	
2701:	3061	3081	
2721:	3081	3101	
2741:	3101	3121	
2761:	3121	3141	
2781:	3141	3161	
2801:	3161	3181	
2821:	3181	3201	
2841:	3201	3221	
2861:	3221	3241	
2881:	3241	3261	
2901:	3261	3281	
2921:	3281	3301	
2941:	3301	3321	
2961:	3321	3341	
2981:	3341	3361	
3001:	3361	3381	
3021:	3381	3401	
3041:	3401	3421	
3061:	3421	3441	
3081:	3441	3461	
3101:	3461	3481	
3121:	3481	3501	
3141:	3501	3521	
3161:	3521	3541	
3181:	3541	3561	
3201:	3561	3581	
3221:	3581	3601	
3241:	3601	3621	
3261:	3621	3641	
3281:	3641	3661	
3301:	3661	3681	
3321:	3681	3701	
3341:	3701	3721	
3361:	3721	3741	
3381:	3741	3761	
3401:	3761	3781	
3421:	3781	3801	
3441:	3801	3821	
3461:	3821	3841	
3481:	3841	3861	
3501:	3861	3881	
3521:	3881	3901	
3541:	3901	3921	
3561:	3921	3941	
3581:	3941	3961	
3601:	3961	3981	
3621:	3981	4001	
3641:	4001	4021	
3661:	4021	4041	
3681:	4041	4061	
3701:	4061	4081	
3721:	4081	4101	
3741:	4101	4121	
3761:	4121	4141	
3781:	4141	4161	
3801:	4161	4181	
3821:	4181	4201	
3841:	4201	4221	
3861:	4221	4241	
3881:	4241	4261	
3901:	4261	4281	
3921:	4281	4301	
3941:	4301	4321	
3961:	4321	4341	
3981:	4341	4361	
4001:	4361	4381	
4021:	4381	4401	
4041:	4401	4421	
4061:	4421	4441	
4081:	4441	4461	
4101:	4461	4481	
4121:	4481	4501	
4141:	4501	4521	
4161:	4521	4541	
4181:	4541	4561	
4201:	4561	4581	
4221:	4581	4601	
4241:	4601	4621	
4261:	4621	4641	
4281:	4641	4661	
4301:	4661	4681	
4321:	4681	4701	
4341:	4701	4721	
4361:	4721	4741	
4381:	4741	4	

SLC1 Gene

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1           21           41
atgagtgtgataggttaggtttctgtattactttaggtccgtgtggcgactggcgctt
1: M S V I G R F L Y Y L R S V L V V L A L
61           81           101
gcaggctgtggctttacggtaatcgctctatccttgcacgtaatcgtaagcaa
21: A G C G F Y G V I A S I L C T L I G K Q
121          141          161
cattggctcagtgattactgcgcgttgcattaccatgtcatgaaattgatgctggc
41: H L A Q W I T A R C F Y H V M K L M L G
181          201          221
cttgcgtcaaggcgttggcgaggagaattggccaagaagccatattatgattgccc
61: L D V K V V G E E N L A K K P Y I M I A
241          261          281
aatcaccaatccacccattggatcatgttaggttaggatcccccggcaca
81: N H Q S T L D I F M L G R I F P P G C T
301          321          341
gttactgccaagaagtcttgcatacgcccccctgggttgcattggctttgagt
101: V T A K K S L K Y V P F L G W F M A L S
361          381          401
ggtacatatttcttagacagatctaaaggcaagaagccattgacacccattgaaataaaggt
121: G T Y F L D R S K R Q E A I D T L N K G
421          441          461
tttagaaaatgttaagaaaaacaacgcgtctatgggtttccctgagggtaccaggct
141: L E N V K K N K R A L W V F P E G T R S
481          501          521
tacacgagttagctgacaatgttgccttcaagaagggtgttccattggcacaacag
161: Y T S E L T M L P F K K G A F H L A Q Q
541          561          581
ggtaagatccccattgttccagtggtttccaaataccagtacttttagtaagtccctaaa
181: G K I P I V P V V V S N T S T L V S P K
601          621          641
tatgggtcttcaacagaggctgtatgattgttagatttaaaacctattcaaccgag
201: Y G V F N R G C M I V R I L K P I S T E
661          681          701
aacttaacaaaggacaattggtaattgtctgtgaaaagtttagagatcaaatgggtgac
221: N L T K D K I G E F A E K V R D Q M V D
721          741          761
actttgaaggagattggctactctccgcattcaacgatacaaccctccaccacaagct
241: T L K E I G Y S P A I N D T T L P P Q A
781          801          821
attgagtatgccgttcaacatgacaagaaagtgaacaagaaaatcaagaatgaggct
261: I E Y A A L Q H D K K V N K K I K N E P
841          861          881
gtgccttctgtcagcattagcaacgatgtcaataccataacgaaagggtcatctgtaaaa
281: V P S V S I S N D V N T H N E G S S V K
901          921          941
aagatgcattaagccaccaccattttagagtagtatataagaccc
301: K M H @

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FIG. 2
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3/7

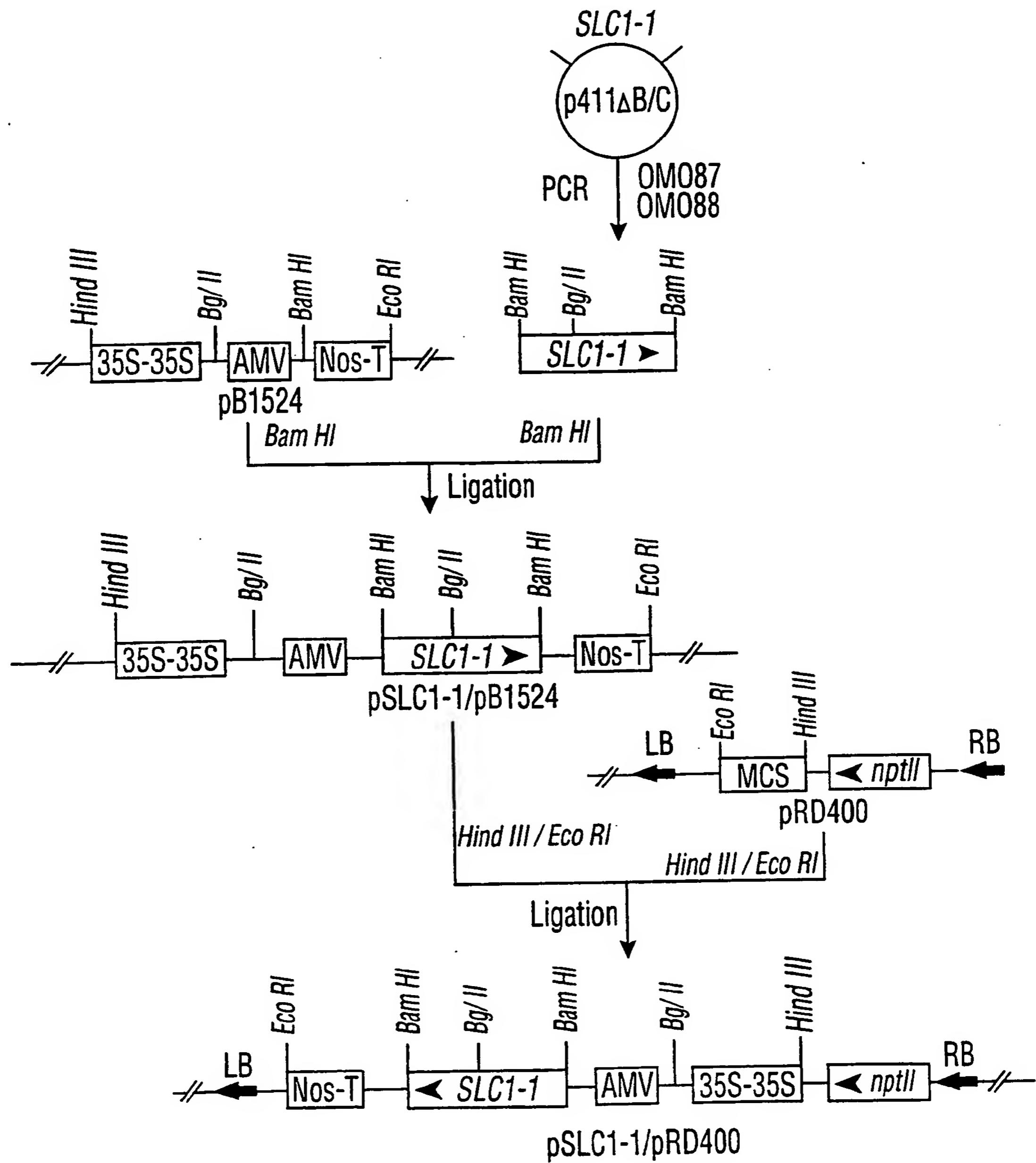


FIG.3 Cloning strategy for constructing SLC1-1 plant transformation vector (salient features not drawn to scale)

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4/7

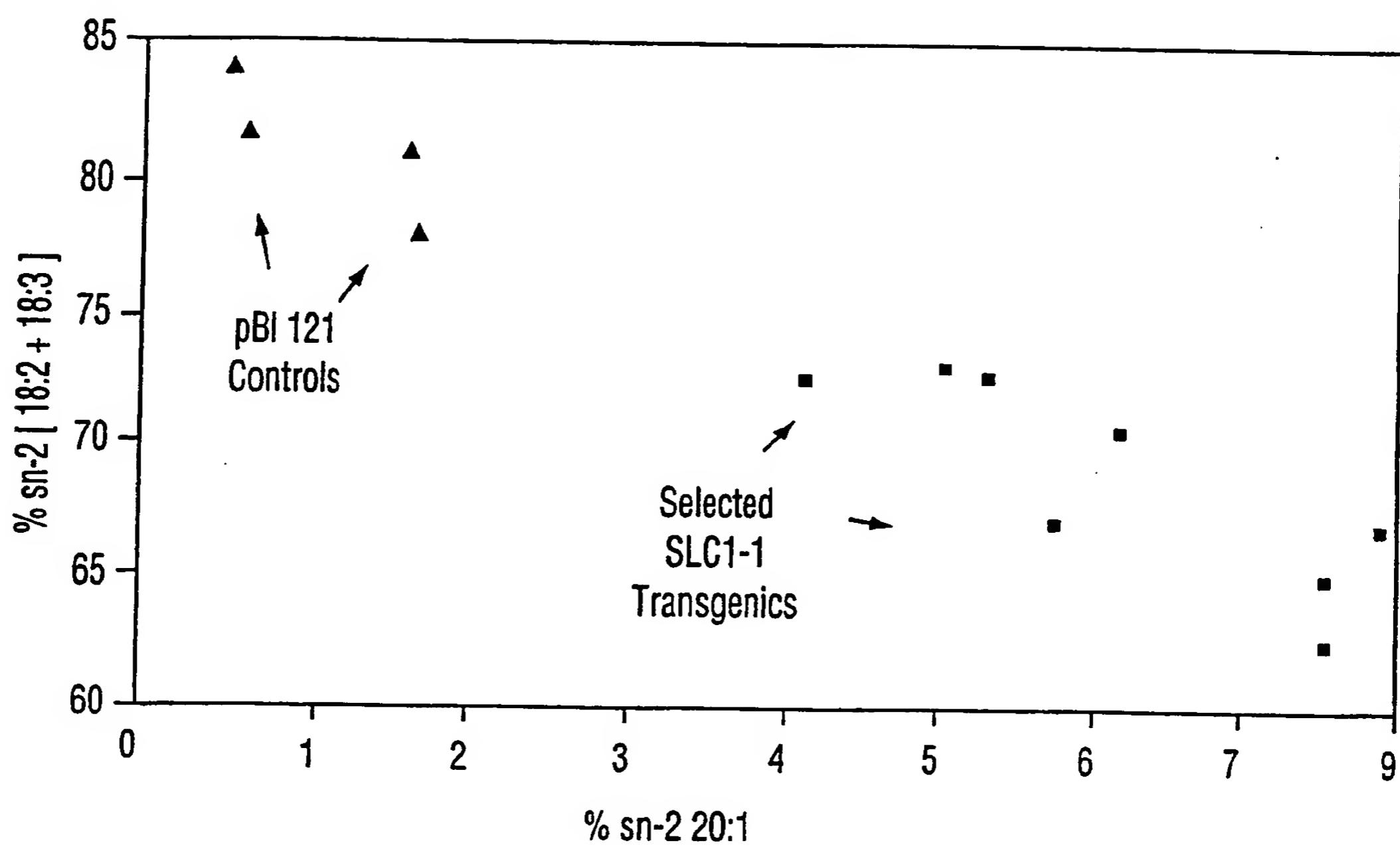


FIG. 4 Correlation between decrease in *sn*-2 polyunsaturated fatty acids and increase in *sn*-2 eicosenoic acid in *A. thaliana* Control and *SLC1-1* Transgenic T_3 Seeds.

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5/7

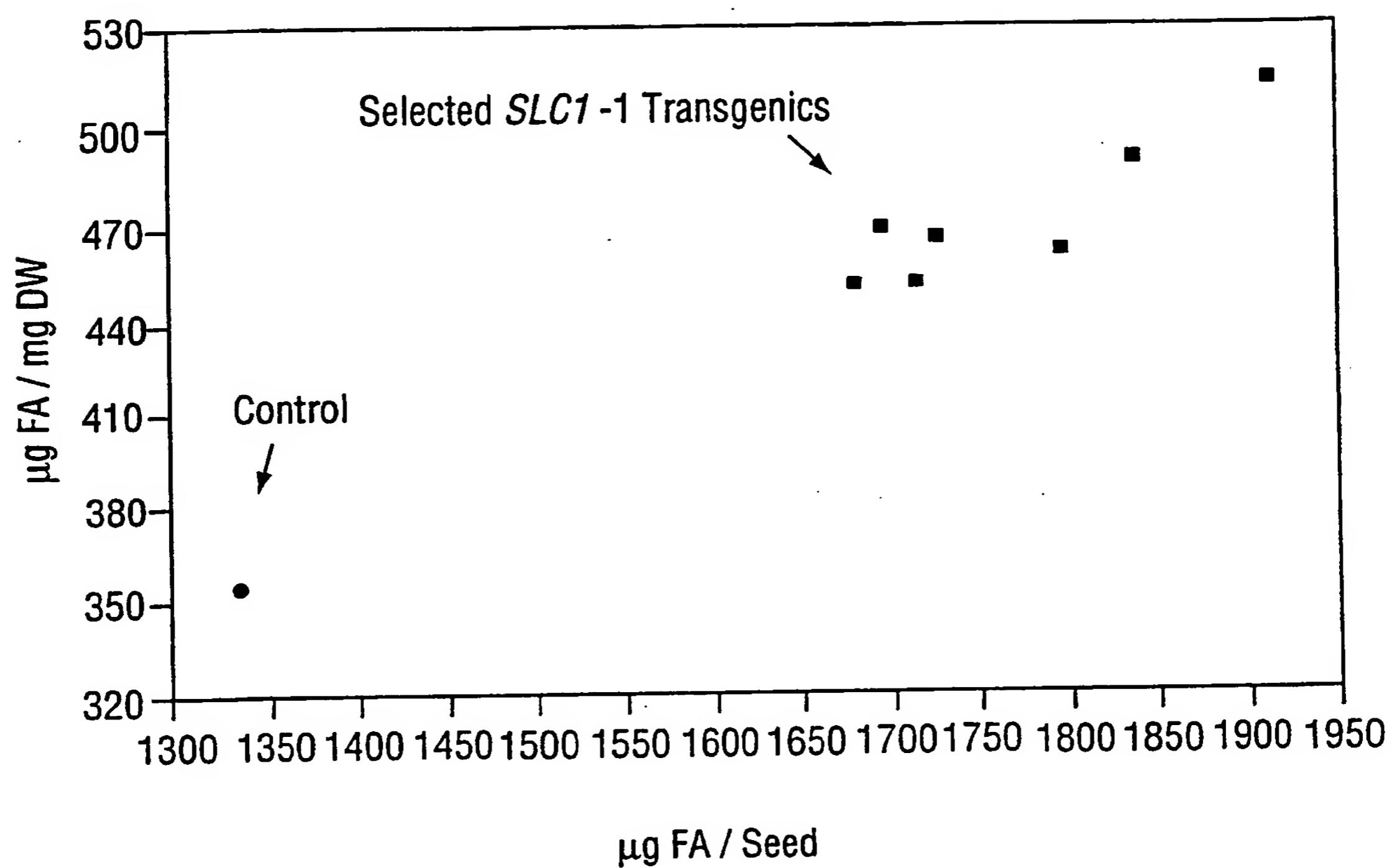
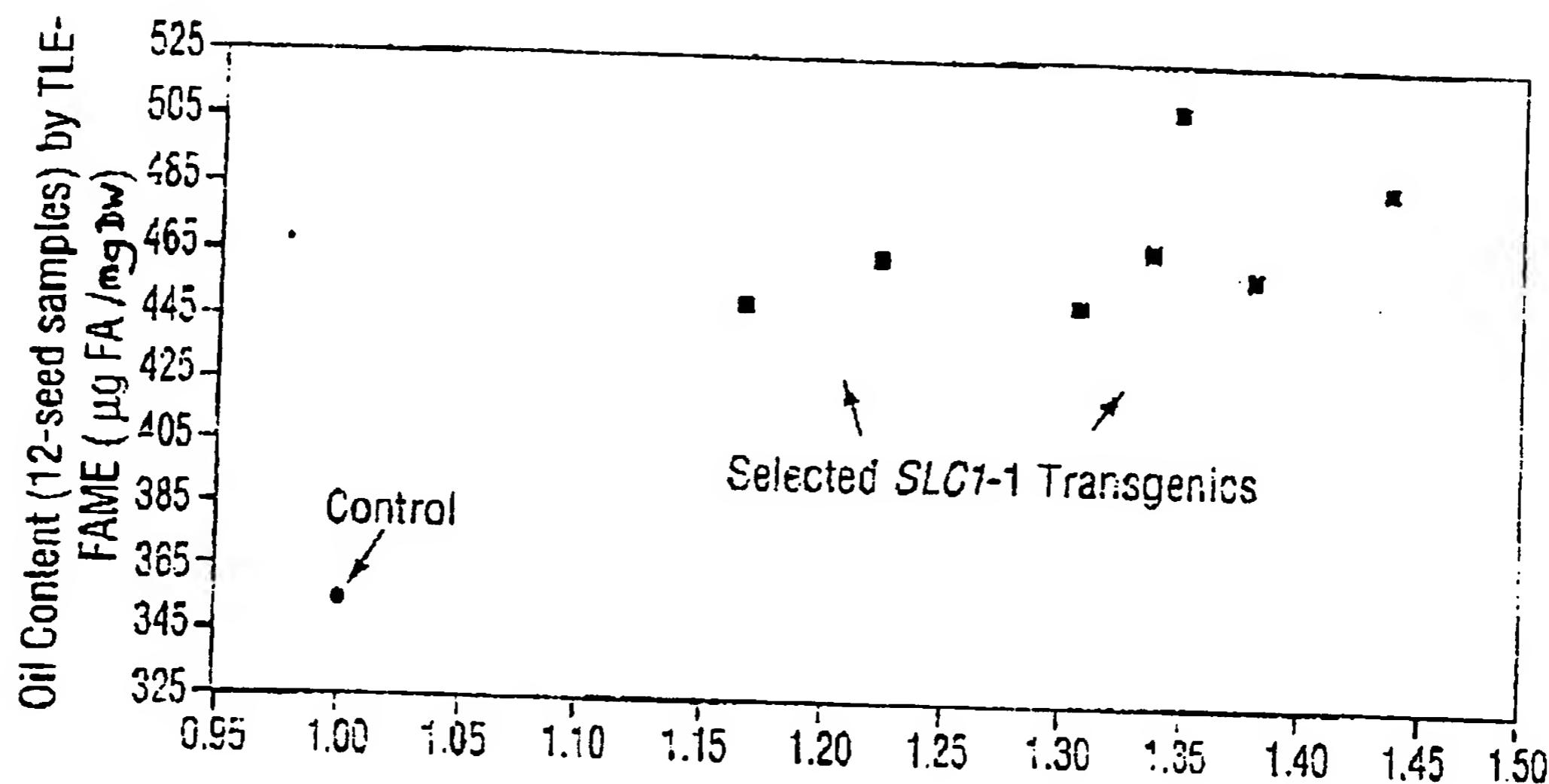


FIG. 5 Correlation of "Fatty Acid Content / Seed" and "Fatty Acid Content / mg Dry Weight" in Untransformed Control and Selected *SLC1-1* Transgenics of *B. napus* cv HERO (12 - Seed Samples)

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6/7

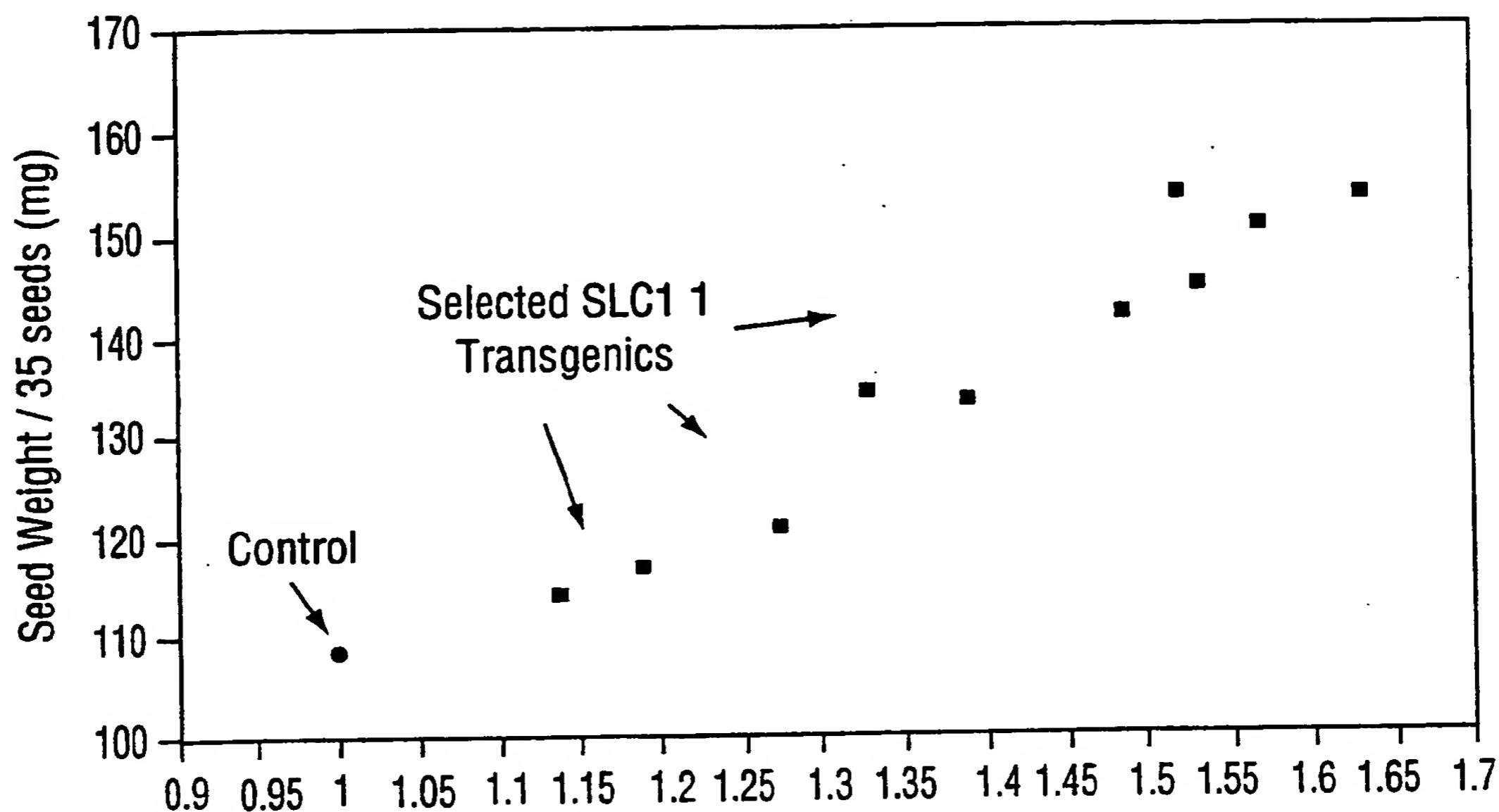


¹H-NMR integral response for resonances assigned to liquid-like oil in
35-seed sample
(Relative to control set at 1.00)

FIG. 6 Correlation Between Relative Oil Content Estimated by
¹H-NMR (non- destructive) Method vs. TLE-FAME (destructive)
Method in Untransformed Control and Selected SLC1-1
Transgenics of *B. napus* cv HERO

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7/7



¹H-NMR integral response for resonances assigned to liquid-like oil in
35-seed sample
(Relative to control set at 1.00)

FIG.7 Correlation Between Seed Dry Weight and Oil Content
(estimated by the non- destructive ¹H-NMR method)
in Untransformed Control and Selected *SLC1-1*
Transgenics of *B. napus* cv HERO

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INTERNATIONAL SEARCH REPORT

Int. ional Application No
PCT/CA 96/00350

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 C12N15/82 A01H5/00 A01H5/10 C12N1/21 C11B1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 C12N A01H C11B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO, A, 94 13814 (NICKERSON BIOCEM LIMITED) 23 June 1994 see the claims. ---	1
A	J. BIOL. CHEM., vol. 268, 1993, pages 22156-22163, XP002013481 M.M. NAGIEC ET AL.: "A suppressor gene that enables <i>Saccharomyces cerevisiae</i> to grow without making sphingolipids encodes a protein that resembles an <i>Escherichia</i> <i>coli</i> fatty acyltransferase" cited in the application see the abstract. --- -/-	1

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

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Date of the actual completion of the international search

17 September 1996

Date of mailing of the international search report

02.10.96

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Authorized officer

Yeats, S

INTERNATIONAL SEARCH REPORT

Int'l. Application No
PCT/CA 96/00350

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PLANT CELL ENVIR., vol. 17, 1994, pages 627-637, XP002013482 S. GIBSON ET AL.: "Use of transgenic plants and mutants to study the regulation and function of lipid composition" see the whole document. ---	1
P,A	WO,A,95 27791 (CALGENE INC.) 19 October 1995 see the claims. -----	1

INTERNATIONAL SEARCH REPORT

Information on patent family members

Int. dional Application No
PCT/CA 96/00350

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
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		CA-A-	2151147	23-06-94
		EP-A-	0673424	27-09-95
		HU-A-	71785	28-02-96
		PL-A-	309327	02-10-95
		SK-A-	76395	13-09-95
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WO-A-9527791	19-10-95	NONE	-----	-----
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